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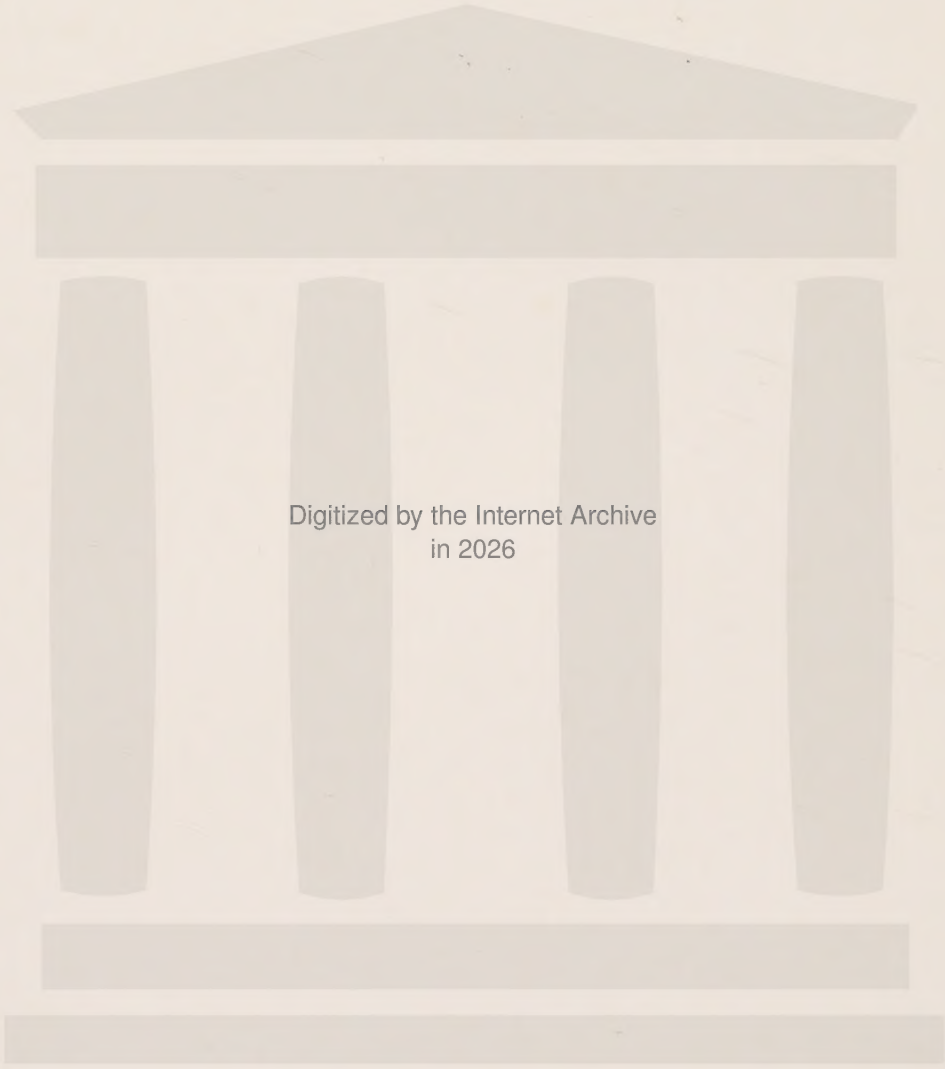

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RESEARCH HIGHLIGHTS 1997•1998

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An annual publication reporting on research of the past calendar year together with a preview of some to be undertaken

Cape Town 1998

Published in 1998 by the Sea Fisheries Research Institute,
Private Bag X2, Rogge Bay 8012, Cape Town

Research Highlights 1997•1998

7

ISSN 1021-1055

Editor

Hans M. Verheye

Layout

Gerald V. van Tonder

Artwork

Cathy M. Boucher
Gerald V. van Tonder
Tony P.van Dalsen

Printed for the Government Printer
by
National Book Printers, Cape Town

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The text was compiled by the Editor from contributions made by the following staff members and co-workers: J. J. Agenbag, R. J. Anderson, C. J. Augustyn, J. M. E. Bailey, M. Barange, D. Calder, A. C. Cockcroft, J. C. Coetzee, R. J. M. Crawford, Z. Davidson, J. A. A. De Oliveira, C. M. Duncombe-Rae, M. D. Durholtz, M. H. Griffiths, J. C. Groeneveld, S. Hart, D. A. Horstman, A. Jarre-Teichmann, A. S. Johnson, F. Le Clus, R. W. Leslie, M. R. Lipiński, R. Maree, D. G. M. Miller, Y. C. Melo, C. L. Moloney, D. J. Needham, G. Nelson, R. Osborne, S. C. Pillar, G. C. Pitcher, A. J. Richardson, M. J. Roberts, B. A. Roel, D. S. Schoeman, L. J. Shannon, H. Smit, M. A. Soule, R. J. Q. Tarr, R. Tilney, C. D. van der Lingen, D. Van Zyl, H. M. Verheye. The Director of the Sea Fisheries Research Institute, Dr A. I. L. Payne, wrote the introduction and laid down the guidelines.

MISSION OF THE
SEA FISHERIES RESEARCH INSTITUTE

The Sea Fisheries Research Institute advises on the utilization of living marine resources and the conservation of marine ecosystems by conducting and supporting relevant multidisciplinary scientific research and monitoring in the marine environment. Sustainable use and the need to preserve future options regarding the utilization of marine ecosystems and their resources are guiding objectives in the research and advice of the Institute. In order to achieve its goals, the Institute advises and interacts with decision-makers, those involved in fishing, interest groups and the local and international scientific community. The Institute conducts its activities in an open and co-operative manner, functions within the Department of Environmental Affairs and Tourism and strives for excellence in its endeavours.

INTRODUCTION

It seems almost impossible that we have already reached the seventh issue of this publication; the first six issues seem to have been impossibly close to each other. When we embarked on this vehicle of publication in the early 1990s, it was with the express aim of separating science and management reporting of Sea Fisheries because, although we are all part of the same organization and weaknesses in one sector would weaken us all, we wanted to emphasize the message that science would be independent of management, especially in such spheres as the granting of access rights to prospective participants in the fisheries. That message has been especially pertinent during the latter half of 1997 and the first part of 1998, while the process of finalization of South Africa's exciting new Marine Fisheries Policy (and its legal instrument, the Act) has been under way. It is important here to give the facts behind the perceived sidelining of scientific input in the drafting of the Act.

Senior scientists of the Institute (and outside) took a very active part in the completion, final publication and publicizing process of the Fisheries Policy (the White Paper released by the Minister of Environmental Affairs and Tourism in May 1997). Thereafter, inputs of the Institute (and other natural scientists) were restricted to the addressing of matters referred by the legal team tasked with drafting the Act and its applied measures, the new Marine Fisheries Regulations. Many inputs were made to this process by scientists, and it is logical that many of them were accepted. However, it is just as natural that many of them were, for reasons other than science, deemed inappropriate for inclusion in either Act or Regulations. Science, it must be stressed, had its say, objected when it was thought that an error of judgement was being made, and ultimately will play a leading role in ensuring that this Marine Living Resources Act, which is a huge improvement on its predecessor, is taken into the new millennium, and made to work to the benefit of all South Africans, as well as the resources traditionally championed by all scientists. The new policy is expected to take effect in the latter half of 1998.

Against this backdrop must be gauged the performance of the Institute as a scientific research establishment during 1997. The same limitation I referred to last year was in place, namely a shrinking real funding base, but it was even more evident than last year. The Institute, as an organ of the State, was also subject to, *inter alia*, the right-sizing and affirmative action policies put in place to correct inadequacies of the past. The first of these policies has meant a reduction (albeit fortunately only a modest one) of the number of posts as personnel have opted for early retirement or an attractive retrenchment package. The second policy has meant that an aggressive internal policy of training scientific and technical personnel from the formerly disadvantaged sector has had to be engaged in. That process is, by its very nature, a long-term one in terms of fully qualified personnel, so only limited success has been achieved to date, despite a carefully conceived training plan being in place. With time, the results of this training plan will become evident, but for now, recruitment of highly qualified persons to replace some of those who have left has become an arduous task, with the limited supply of candidates available. Added to these personnel limitations, the shrinking funding base has meant that opportunities for sea-based research have shrunk with a lessened research fleet operating budget and reduced capacity for planned maintenance on the same fleet. Only top-priority research cruises were undertaken during 1997, though chances for opportunistic data collection on those same cruises meant that all was not lost nor all long-term data series interrupted.

What has been said above would tend to leave

the reader anticipating a poor research performance by the Institute during 1997. However, that is most certainly not the case, as the contents of the pages that follow will testify. Institute scientists have faced the problems head-on, and the quality of the research output has not diminished; in some spheres it has indeed improved. Innovative means have been employed to collect the information necessary to manage the living marine resources optimally, and a much greater level of involvement with participants in the fisheries (fishers, managers and communities) has allowed for greater knowledge, if not understanding, of the processes which cause our resources to fluctuate in the seemingly unpredictable manner shown by catch records. South African science can be justifiably proud of the interactive (with stakeholders) manner in which fisheries research leading to better management has been undertaken. The Marine Fisheries White Paper gratifyingly entrenches that interaction in policy, and the personnel corps of the Institute have grasped the opportunity with both hands. Such action can only lead to better fisheries management, and hopefully also to improved understanding of why certain decisions have had to be made in the interests of stock sustainability.

The Institute places great hope on the results of collaborative research programmes, an arena that has blossomed in the past few years. Obviously, in terms of current State policy, sub-Saharan Africa has had to be the focus. The BENEFIT (BENguela Environment Fisheries Interaction and Training) project was launched under the aegis of the Southern African Development Community in April 1997. South African researchers are poised to play a leading role in that (10-year) project, hopefully helping it to fulfil many of its broad objectives. Fortunately, two generous sponsors (one each from Germany and Norway) are ensuring that the funding limitations dogging the national research programme are at least partially overcome in a regional sense. With an Executive Officer now appointed and funding almost guaranteed, prospects for the next few years are excellent. Of course, there are some positive national spin-offs from this regional involvement, and South Africa will be quick to grasp them. An allied programme of the same three coastal states, Angola, Namibia and South Africa, the Benguela Current Large Marine Ecosystem (BCLME) project, is also poised to take off, subject to World Bank support. More of an environmental programme than BENEFIT, the BCLME study will complement the outputs of BENEFIT and feed meaningful knowledge about how the whole system functions and, *inter alia*, influences meteorological conditions over the subcontinent, so providing valuable knowledge for the coastal states' decision-making structures.

Essentially, one should try not to focus on the highlights in an introduction such as this as one runs the risk of understating the importance of certain research endeavours. Therefore, I would rather refer the reader to the pages that follow and just mention a few high points in terms of events and policies that are particularly deserving of mention (even though they are addressed in detail elsewhere). In September 1997, a highly successful cephalopod symposium was hosted jointly by the Institute and the South African Museum. International visitors spoke highly of it, and the symposium proceedings (due to be published in 1998) will no doubt show how well the small South African pool of cephalopod researchers are respected internationally, and why that situation prevails. The next symposium of marine interest to be hosted jointly by the Institute (with the University of Cape Town this time) is an ICES (International Council for the Exploration of the Sea) event on the broad, but crucial topic "Confronting Uncertainty in Fisheries Management". The Institute is privileged to have been granted the organization of such a prestigious symposium outside the borders of the 19 member states of ICES. Finally, I have to mention the contributions by Institute researchers towards ensuring that South Africa supports the principles of sustaining biological diversity. Ably assisted by several scientists from other South African research institutions, our Marine Protected Area programme is rapidly taking the shape of a policy. Massive, probably international, funding is going to be

necessary to fulfil the laudable objectives of the programme if South Africa's hard-earned international respect for its Marine Protected Area system were to be retained, but researchers at the Institute are working hard to position the country to achieve just that.

In closing, I must stress that the strength of South African marine science does not rest solely with the Institute. Networking with scientists in other institutions and collaborative ventures, conducted in a spirit of determination to succeed in the face of all odds, has allowed the country to retain its marine science power base and to face the rest of the world as equals. Fishing industry support to a levy fund aimed at preserving the level of scientific output has also played its part and, with the promise of greater fishing-derived inputs to a fisheries management and administration fund, the new Marine Living Resources Fund, the future is not all that pessimistic. Indeed there is room for much optimism.

Pelagic fish

The first half of the 1997 pelagic fishing season was unusual in that no fishing for anchovy *Engraulis capensis* was allowed. This restriction followed the all-time low biomass of 143 000 tons estimated during the November 1996 survey (Fig. 1a). In contrast, the sardine *Sardinops sagax* stock appeared to be in a relatively healthy state, having increased steadily from its low levels during the mid 1980s to 505 000 tons. These observations necessitated the development of a new management procedure for sardine which assumed no directed fishing for anchovy during 1997; hence there would be no need to address the usual by-catch problem of juvenile sardine. Previous studies had shown extreme sensitivity of the sardine stock to the magnitude of this by-catch, so setting the latter to zero resulted in a higher

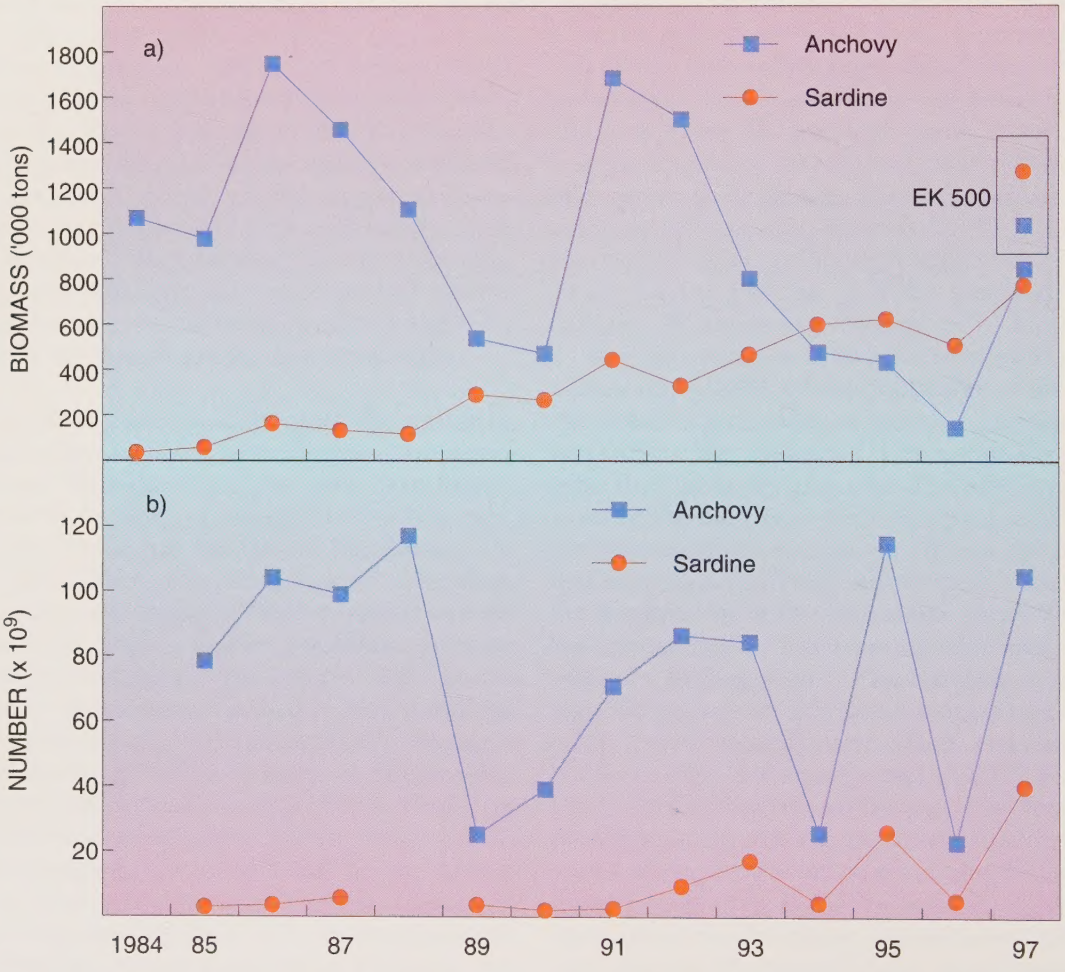

Fig. 1: Time-series of (a) end-of-year estimates of anchovy and sardine spawner biomass, 1984–1997, and (b) mid-year estimates of anchovy and sardine recruits, 1985–1997

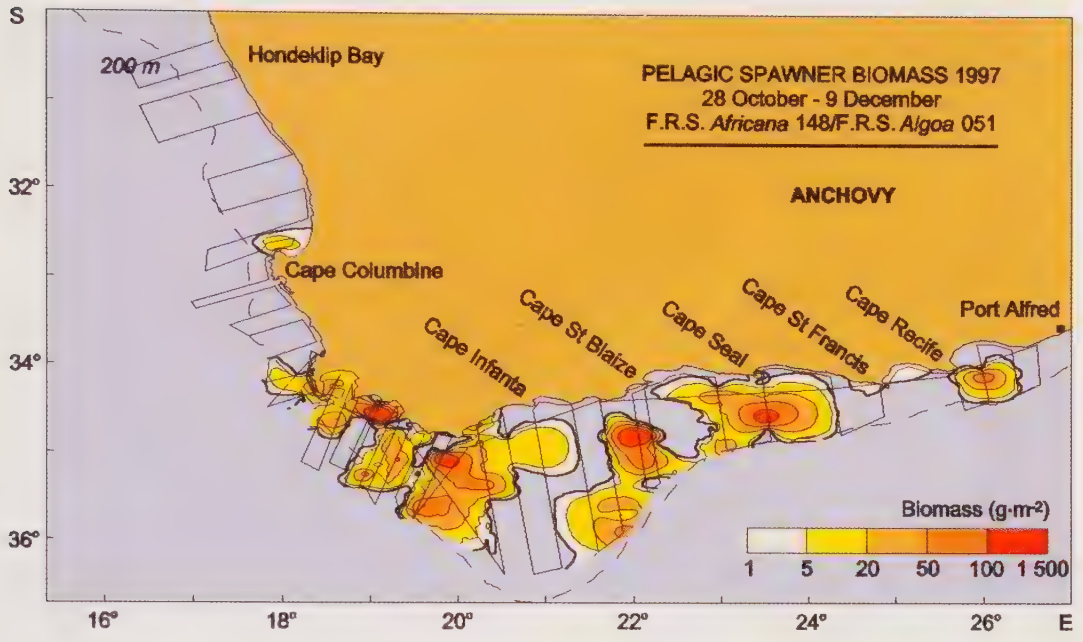

Fig. 2: Distribution and relative abundance of anchovy during the 1997 Pelagic Spawner Biomass survey

sardine-directed Total Allowable Catch (*TAC*) than would otherwise have been the case.

Perceptions changed after the mid-year pelagic recruit survey in 1997, when average recruitment of anchovy and good recruitment of sardine were evident (Fig. 1b). Analyses indicated that re-opening the anchovy fishery, which would immediately result in fishing mortality of juvenile sardine, would not compromise levels of future directed fishing for adult sardine anticipated by the new management procedure for sardine. The approach used was to ensure that the quanta set for anchovy *TAC* and juvenile sardine by-catch allowance would provide sufficiently high probabilities of achieving end-of-year target biomass levels, while still taking the anchovy-to-sardine ratio which prevailed at the time of the recruit survey into account.

It appeared too that, contrary to the philosophy of pelagic fish management, there may have been some targeting on adult sardine while declaring it as by-catch, so it was considered imperative to put forward clear guidelines as to when landed sardine could be declared as by-catch, and when not. A study was therefore undertaken focusing on the percentage sardine encountered in all pelagic landings over the period 1994–1997. Most of the landings were found to contain either 30% or less sardine, or 70% or more. Furthermore, most landings constituting 30% or less sardine were by-catch, whereas landings with 70% or more sardine were mostly sardine directed. A level of 50% was therefore considered as an appropriate cut-off point for determining whether the adult sardine in a landing ought to be regarded as by-catch or directed catch.

Results from the November 1997 spawner biomass survey indicated a substantial increase in the parent stock size of both anchovy and sardine (Fig. 1a), in line with their improved recruitment observed earlier in the year. Anchovy were widely, albeit unusually patchily, distributed over the Agulhas Bank (Fig. 2), whereas sardine were concentrated mostly in the inshore regions of the western Agulhas Bank, with surprisingly few shoals east of Cape St Blaize (Fig. 3).

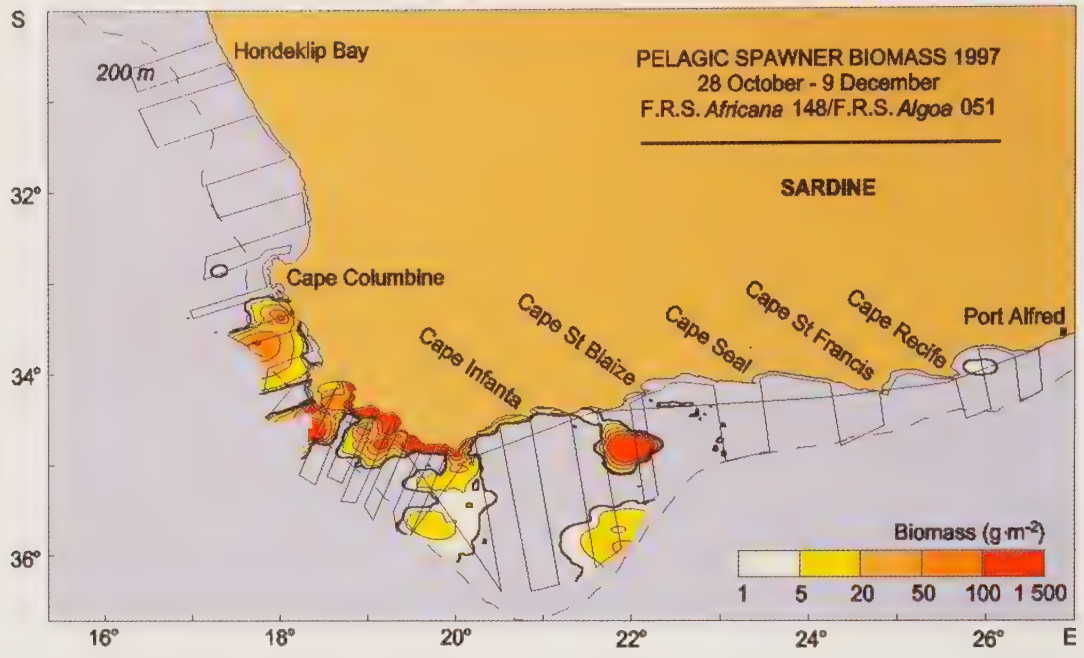

Fig. 3: Distribution and relative abundance of sardine during the 1997 Pelagic Spawner Biomass survey

A new echosounder, the Simrad EK500, and associated processing software were used for the first time during both the recruit and spawner biomass surveys in 1997. Previous performance comparisons between this system and the old EK400 showed similar sensitivity responses except for very high back-scattering values (see *Research Highlights* 1996/1997: Fig. 24). Following the relatively high estimates of biomass obtained during the 1997 surveys, there was concern about the comparability of the old and the new systems, particularly when very high fish densities were encountered. Using the old EK400, such densities would have caused an underestimation of the actual biomass, so making the most recent estimates using the EK500 not comparable with the previous ones in the time-series (Fig. 1a). Results from tests indeed showed that the EK500 estimates were some 20% higher for anchovy and 40% higher for sardine than those obtained using the EK400. Although it has been possible to adjust the EK500 results to make them comparable with previous years' estimates, it is emphasized that the 1997 measurements of anchovy and sardine biomass are considered to be the most accurate estimates of their respective population levels possible with current technology.

Unlike the six previous pelagic pre-recruit surveys, which were restricted to within 70 miles of the coast on the nursery grounds off the West Coast, the survey in March 1998 extended offshore to 130 miles to determine the full extent of the distribution of both anchovy and sardine pre-recruits. Similar to previous years, anchovy pre-recruits were distributed over the entire West Coast nursery area, with longshore and cross-shelf gradients evident in their size distribution (Fig. 4). Larger, older pre-recruits were inshore, with highest concentrations in the north, whereas smaller, younger pre-recruits were offshore, with peak densities in the south. Small pre-recruits were much more abundant than large ones. Some were collected at the most-offshore stations of the 130-mile lines, suggesting that the offshore extent of their distribution may not have been surveyed in previous years. Sardine pre-recruits were present at much lesser abundances, and had a much patchier distribution, than anchovy pre-recruits.

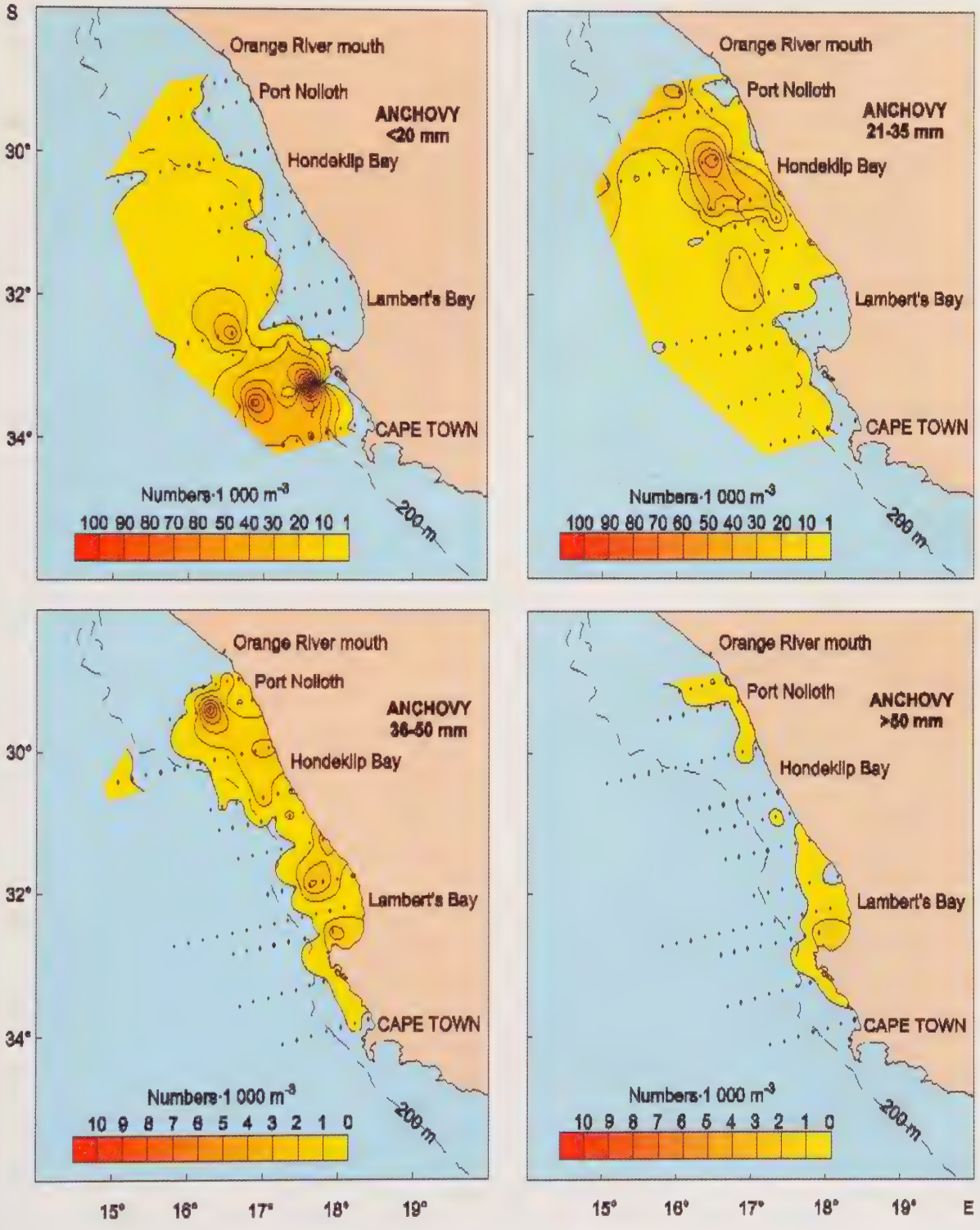

Fig. 4: Spatial distribution of four size-classes of anchovy pre-recruits caught by the Methot net during March 1998

Besides information on the abundance and distribution of pre-recruits, the surveys also provide an early indication of recruitment strength for each species, based on a pre-recruit abundance index for the West Coast nursery area. This index is calculated as the average number of pre-recruits per 1 000 m^3 within the survey area from Cape Columbine to the Orange River. The anchovy pre-recruit abundance index for 1998 was slightly higher than that for 1997, whereas that for sardine decreased by about 50% (Fig. 5). The substantial increase in the number of anchovy pre-recruits captured can be attributed partly to the increased number of Methot hauls used to sample the smaller, younger pre-recruits which cannot be detected acoustically. In contrast to previous years, however, fewer fish were detected acoustically over the entire West Coast, and very poor catches of larger, juvenile anchovy or sardine were made with the midwater trawl. This scarcity of recruits on the West Coast may be linked to the fact that most adult anchovy were found east of Cape Agulhas during the November survey (Fig. 2), suggesting that eggs and larvae produced at that time may not have been transported successfully to the West Coast nursery area. The results from the 1998 survey indicate that anchovy recruitment to the West Coast is likely to be later than usual, the recruitment strength depending on the survival of the moderate quantities of pre-recruits encountered there.

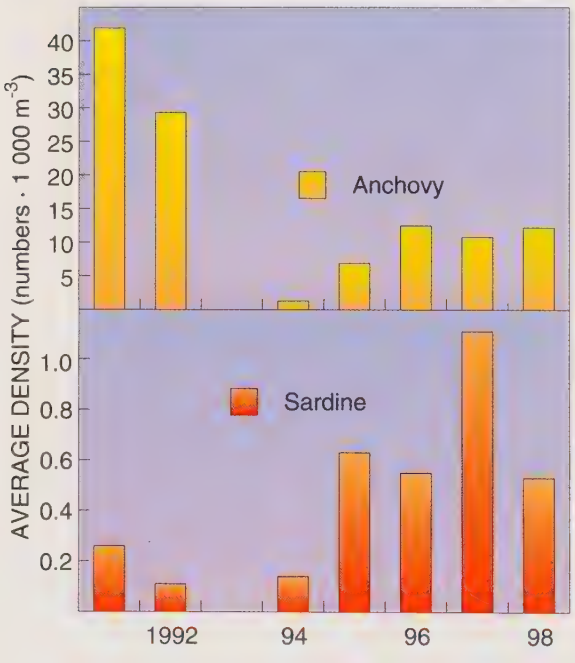

Fig. 5: Time-series of the abundance index of anchovy and sardine pre-recruits on the West Coast north of Cape Columbine, 1991–1998

Demersal fish

Stock assessment and monitoring of the status of Cape hakes *Merluccius paradoxus* and *M. capensis* remain the primary concern of demersal research at the Institute. An Operational Management Procedure (OMP) for the Cape hakes, the development of which is near completion, will be the final result of extensive statistical testing of various candidate management models that were chosen in consultation with the fishing industry. The OMP includes a suite of checks and balances which are implemented for the fishery and serve to maintain the stock and the *TAC* at levels decided upon through consultation with the fishing industry. The hake stock assessment surveys indicate that the biomass of West Coast hakes has increased over the past 15 years. In contrast, the general linear model (GLM) standardized catch rates, which account for any quantifiable effects or biases, show a negligible increase over this period. This discrepancy is thought to be related to a change in fishing strategy towards targeting of larger hake, which has resulted in a smaller proportion of the total biomass being available to the fishery. These two effects are balanced so that, although the total biomass has increased, the exploitable biomass has remained almost constant. This accounts for the apparent conflict between the survey estimates, which track the total biomass, and commercial catch per unit effort (*cpue*), which shadows the fishable biomass (Fig. 6).

The 2-year experimental longline fishery for hake was concluded at the end of 1997. Data on

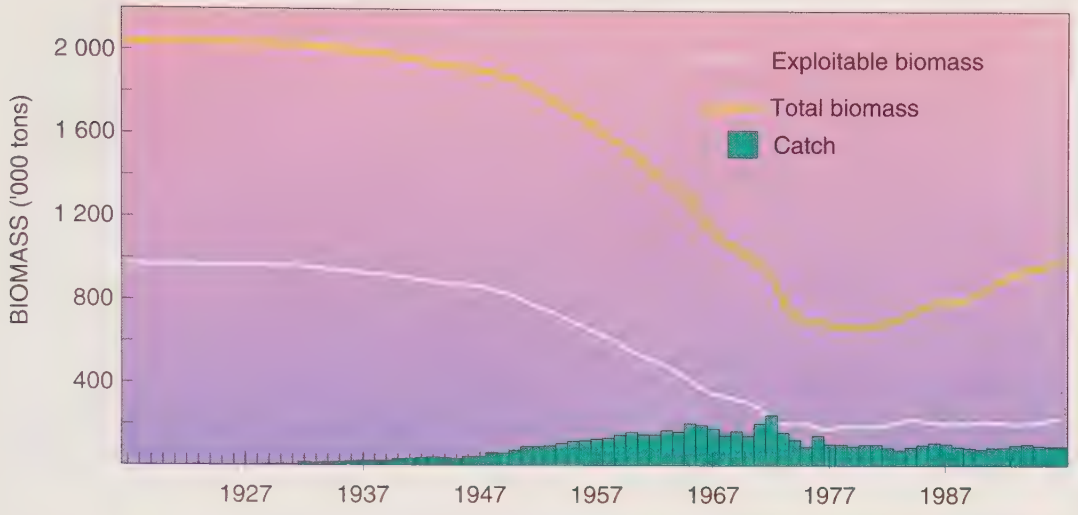

Fig. 6: Time-series of catches of Cape hake on the West Coast (1917–1997), and estimates of total and exploitable biomass based on an age-structured production model

catch rates, selectivity patterns, sex ratios and species composition of catches are being analysed. One of the primary findings is that longlining selects large individuals, 50% recruitment taking place at a length of 65 cm, as opposed to only 33 cm in the trawl fishery (Fig. 7). Further, the sex ratio of the catch was skewed significantly toward females. Preliminary modelling results indicate that, from a biological point of view, longlining is the preferred method for harvesting hake under most assumptions of selectivity and mortality. However, recent work using age-structured production models has indicated that natural mortality rates for hake may be much higher than previously thought. This finding has considerable bearing on the preferred age or size at selectivity for the fishery. It suggests, contrary to earlier findings, that it may be preferable for hake to be recruited at a relatively small size, favouring trawling. An additional cause for concern is the observed bird mortalities during the experimental longline fishery; identifying effective ways of reducing this controversial by-catch requires additional research.

The Agulhas sole *Austroglossus pectoralis* resource is assessed using Virtual Population Analysis (VPA), which follows an age-class from entry into the fishery (Age 3) to the oldest age (Age 9). The model back-calculates fishing mortality and is then calibrated to absolute values of abundance by tuning it either to the survey biomass index or to *cpue*. However, there are reservations as to the reliability of the VPA assessment because the model does not accurately reflect the trends shown in the time-series of survey biomass estimates and *cpue* indices (Fig. 8). As a result, a cautious approach has been adopted and a constant catch strategy has been applied to the resource since 1993. GLM analyses of the sole *cpue* to obtain a standardized *cpue* time-series have not yet been performed. The main problem with the *cpue* is that there is a larger seasonal than interannual variation in the catch rates of sole, implying that *cpue* is an imprecise index of abundance for Agulhas sole. Factors which could affect the availability and bias the catch rate of sole are currently being investigated in an effort to improve the *cpue* time-series. Some of the results of this research are discussed later.

In the absence of a reliable *cpue* time-series for horse mackerel *Trachurus trachurus capensis*, a yield-per-recruit type modelling approach has been adopted. This model determines the

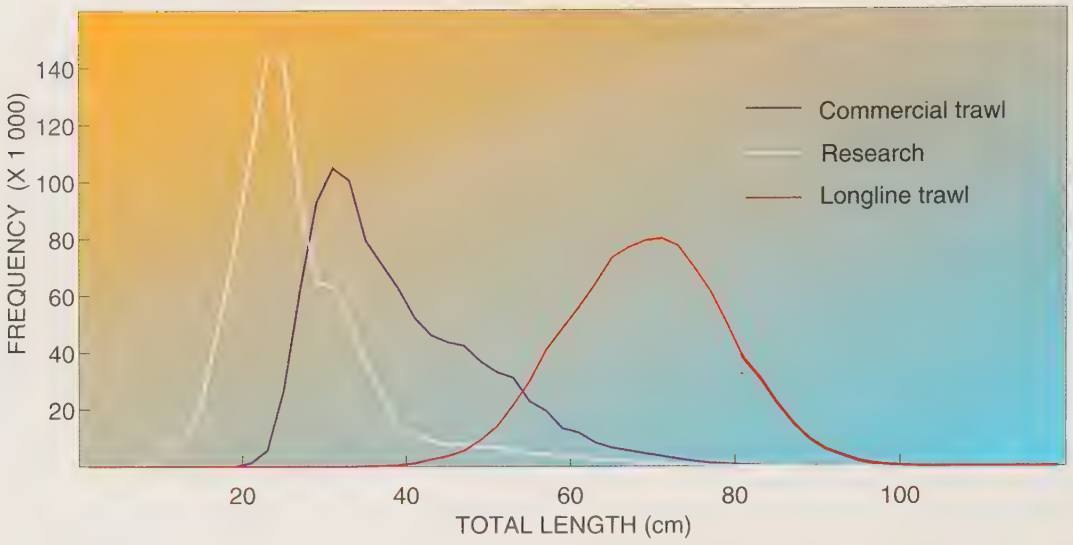

Fig. 7: Size selectivity of research trawl (F.R.S. Africana*, 37.5-mm mesh), longline and commercial trawl (110-mm mesh) in capturing Cape hake*

proportion of the estimated survey biomass that can be harvested, to produce an equilibrium maximum sustainable yield. In addition, a safety factor has been built into the model, designed to ensure that the probability of the spawner biomass falling below 20% of the 20-year mean pre-exploitation biomass is <10%. Horse mackerel is a low-value fish and targeted fishing using midwater gear yields a narrow profit margin. As a result, the annual Precautionary Maximum Catch Limit (PMCL) has been undersubscribed for several years. During 1997, a large Russian midwater trawler entered the fishery, under a joint-venture agreement, and was deployed to catch the horse mackerel quota of several local fishing companies, perhaps marking a turnround in this underutilized fishery.

As competition for commercial species increases,

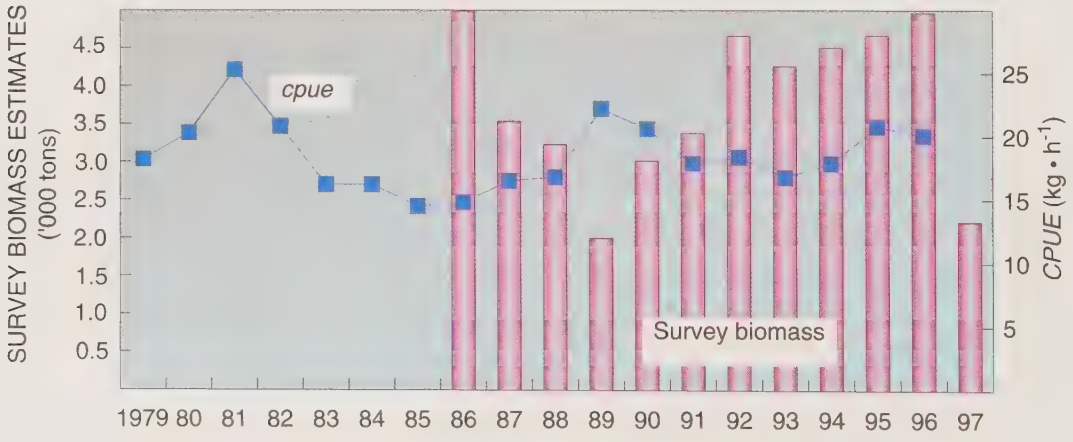

Fig. 8: Time-series of Agulhas sole cpue *and survey biomass, 1979–1997*

greater emphasis is being placed on by-catch species. However, there is a paucity of data on the majority of these species in terms of their basic biology, distribution and abundance. Through the use of an observer programme and studies of individual species, a multi-institutional by-catch research programme aims to provide the data required to assess the possibilities for enhanced utilization of such species. Research projects have been initiated to investigate the biology, exploitation and management of six important by-catch species. Overall, 1997 was a successful year for the observer programme, which monitored some 400 trawls on the West Coast, 350 near Mossel Bay and 100 in the Port Elizabeth area. Three permanent observers, operating from Cape Town and Mossel Bay, ensured the constant collection of data and biological samples. Input of data into a specially designed database is ongoing, and will support investigations into the abundance and distribution of monkfish *Lophius vomerinus*, rattails *Coelorinchus simorhynchus*, *C. braueri* and *Malacocephalus laevis*, Cape dory *Zeus capensis* and jacopever *Helicolenus dactylopterus* during 1998.

The exploratory deep-water trawl fishery for orange roughy *Hoplostethus atlanticus* (Fig. 9) and oreo-dories has entered its third year and, in total, four permits have been issued. A preliminary biomass assessment study, based on all catches up to June 1997, showed that orange roughy are present at very low densities along the West Coast (the East Coast has not yet been surveyed). A "trigger level" catch limit of 500 tons has been set for the species. Should this limit be reached, a set of management and assessment procedures will come into play in order to reach consensus on whether fishing should continue. A Defined Management Area (DMA) for oreo-dories has been identified along the south-western slope of the Agulhas Bank, with a catch limit of 1 000 tons. Outside of this DMA, a 500-ton "trigger level" catch limit for oreo-dory has been set, as for orange roughy. Approximately 630 tons of oreo-dory and 1–2 tons of orange roughy were landed during 1997. The results of a biological investigation on some of these species are presented elsewhere in this publication.

Linefish

The South African linefishery is a multi-user fishery exploiting more than 200 species, of which 95 contribute the bulk of catches. The fishery includes substantial recreational and commercial sectors. The commercial sector

Fig. 9: Orange roughy Hoplostethus atlanticus *(courtesy of A. Rees, Suidor Fishing)*

comprises some 3 000 boats which operate on the continental shelf in depths of 5–100 m. The recreational sector includes estuarine anglers who fish from boats (c. 50 000) or river banks (numbers unknown), rock-and-surf anglers (c. 400 000), and a recreational lineboat sector (>4 000 boats and c. 12 800 anglers) which operates in a similar environment to the commercial component. The linefishery, excluding the estuarine component, is estimated to provide employment for more than 130 000 persons and generates a revenue to the tune of c. R2.2 billion per year to the four coastal provinces.

The origins of the South African linefishery can be traced back to the fishing activities of European seafarers and indigenous Khoi in the 1500s. The Dutch colonized the Cape in 1652, but because of various restrictions, the fishery was slow to develop, despite an abundance of fish. However, when the British captured the Cape Colony in 1795, all fishing restrictions were lifted, and by the mid 1800s the linefishery had become a thriving industry. The next spurt in the growth of the fishery took place after World War II when both fishing effort and linefish catches increased substantially. This resulted from the simultaneous introduction of motorized vessels, the construction of small-boat harbours along the coast and the availability of echo-sounding technology. The total annual catch peaked in the late 1960s and has declined steadily since then, despite a continual increase in the number of fishers. Catches of species such as seventy-four *Polysteganus undulosus*, red steenbras *Petrus rupestris*, dageraad *Chrysoblephus cristiceps*, carpenter *Argyrozona argyrozona* and geelbek *Atractoscion aequidens* have also dropped dramatically.

The first attempt at managing linefish resources was marked by the introduction of minimum size limits for selected species in 1940 but, in the absence of life-history information, these regulations were determined on a fairly arbitrary basis. As a result of growing concern for the linefish resource, biological studies on a few important species (e.g. carpenter, seventy-four, hottentot *Pachymetopon blochii*) were initiated in the late 1960s. A decade was to pass, however, until the fishery was to receive research attention that was consonant with its status. With the exception of a closed season for elf (shad) *Pomatomus saltatrix* in KwaZulu-Natal, and snoek *Thyrsites atun* in the Cape, no other restrictions were promulgated until a comprehensive management framework was introduced for the linefishery early in 1985. Included in this framework were: the introduction of a two-tiered licence system for commercial fishers (full-time [A-category] and part-time [B category]); freezing of the commercial effort at the 1985 level; the introduction of minimum size limits based on the sizes-at-maturity; the categorization of linefish species based on their perceived vulnerability to exploitation, with associated bag limits for commercial and recreational fishers; and the introduction of national closed seasons for certain species. One of the main objectives behind this initiative was to steer fishing effort away from "vulnerable" reef fish species to the more "resilient" shoaling species. Although species categories and size limits were revised in 1992, the management framework has, in essence, remained unchanged. Owing primarily to a lack of biological and fisheries data, the level of protection afforded to each species has depended largely upon subjective perceptions of its vulnerability to exploitation, rather than on quantitative evaluations. Furthermore, the absence of clear management guidelines and the existence of strong user lobby groups have resulted in considerable compromise.

Recent research surveys reveal that fishers rarely attain the bag limits. In some respects current regulations therefore fail to limit the catches of linefish species. In addition, catch rates for many species have continued to decline and stock assessments indicate that many of the so called "resilient" species (e.g. kob *Argyrosomus* spp.) are actually severely overexploited. As a result of these findings as well as the introduction of a new Marine Fisheries Policy for South Africa, a workshop was convened in July 1997 to review the management of the linefishery. This

workshop was attended by fisheries scientists and managers from organizations throughout the country. The proceedings of the workshop are currently being used to formulate a new Management Plan which will launch linefish management into a new era. Key features of the new plan include clearly defined management objectives, attained via OMPs which incorporate assessment-based management regulations, and greater user-group involvement. The new management plan also calls for major changes to the monitoring of the fishery.

The above-mentioned surveys also revealed that current systems for the collection of linefish *cpue* data, comprising compulsory commercial catch returns and voluntary recreational returns, are inadequate in terms of both accuracy and user-sector coverage. As a result, these data will in future be collected by observers at key geographical positions. The pilot phase of this observer programme is scheduled to be launched in 1998.

Snoek is an important trawl and linefish species off the South African west coast. It is also one of the major predators of the Benguela ecosystem, preying mainly on sardine, round herring *Etrumeus whiteheadi* and anchovy. However, the species has received little research attention in terms of its productive capacity, and as a result enhanced management of the stock has not been possible. A project investigating the life history of West Coast snoek was therefore initiated in 1995. It has been established that the length-at-50%-maturity is 78 cm (i.e. at 3 years old), and that spawning takes place offshore (200–400 m depth) during winter and spring (June–October). Given that snoek grow extremely fast until they reach maturity, it is envisaged that increasing the minimum size above the current 60-cm limit (Fig. 10) will substantially improve the yield from the resource. An increased size limit will also ensure a larger spawner biomass, which will guard against recruitment overfishing. The snoek project has recently been expanded to

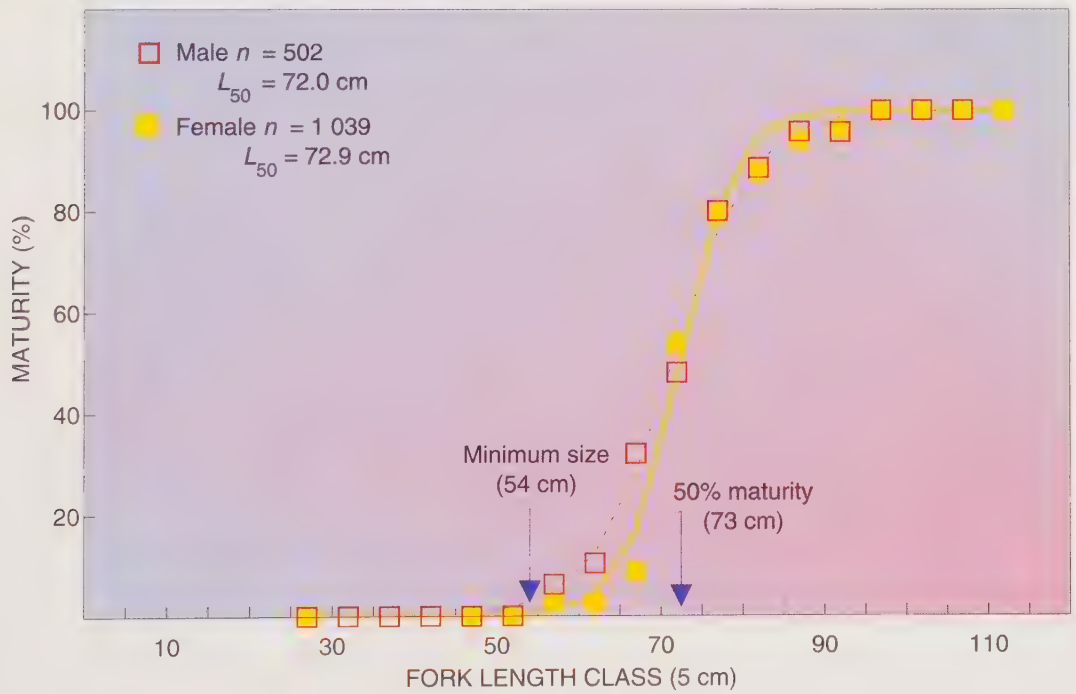

Fig. 10: Snoek size-at-maturity, expressed as the proportion of mature snoek in 5-cm fork length intervals, with an indication of the current minimum size limit (54 cm fork length = 60 cm total length) and the length-at-50%-maturity (73 cm fork length = 78 cm total length)

investigate diel spawning patterns, as this will provide more insight into the impact that trawling may have on the offshore spawning aggregations. Dietary studies are also under way, providing information on the ecological role that snoek play in the Benguela ecosystem. They will be useful in determining the effects of overfishing on both the predator and its major prey species.

In response to considerable pressure for increased access, and many other controversial issues surrounding the small-net fishery, a programme on the management and socio-economics of the South African beach-seine and gill-net fishery was initiated in 1996. The main objectives of this initiative were: to assess the impact of the netfishery on linefish, harder *Liza richardsoni* and chondrichthyan resources; to establish areas which can support additional effort; and to determine criteria for the selection of new participants. This research has four components: (i) the monitoring of catches made by the netfishery; (ii) an investigation into the stock structure and population dynamics of the harder resource; (iii) a socio-economic survey; and (iv) a programme of experimental netting.

Other research projects currently conducted include one on the life history and management of carpenter and another on the impact of inshore trawling on linefish stocks. The carpenter project is due to be completed by the end of the year 2000, and the inshore trawl project by the end of 1999.

Cephalopods

During 1997, Sea Fisheries received several applications for permits to exploit octopods. Lacking knowledge about this latent resource, and with a view to assessing the scope for a commercial fishery to be established, an experimental fishery has been proposed. Such an approach would allow the collection of biological data required to determine the sustainability of the resource. The experiment will probably commence during 1998 and will, besides giving insight into the distribution and abundance of octopods, provide an opportunity for needed taxonomic studies. Basic biological parameters such as length, mass and maturity state will be measured routinely.

As in previous years, the main research effort in 1997 focused on chokka squid *Loligo vulgaris reynaudii*. The dynamics of the stock on the South Coast spawning grounds were modelled to assess the effects on the resource of current effort levels and the existing closed season. Model results indicate that the biological and economic gains provided by the current closed season are limited, and that there is questionable justification for urgent action to curtail current effort levels. However, in view of the apparently high risk associated with the current effort levels and the high sensitivity of the results to basic model assumptions, maintaining the closed season and avoiding increases above the current level of effort have been recommended. Indeed, the effort level may need to be reduced if sustainability is to be ensured, and the option of extending the existing closed season to effect this may well prove easier to implement than any attempt to reduce the present number of participants in the commercial fishery. A workshop held at the beginning of 1998 to review the management of chokka squid in southern Africa underlined the importance of effort control. However, the results of the workshop are still being processed and need to be refined before any firm recommendations concerning management can be made.

Preliminary findings of a random survey undertaken to assess catch and effort of the recreational fishery for chokka indicate that this user sector does not seem to have a large impact on the resource, because their catches are small. The contradictory trends in squid abundance indices derived from commercial trawl statistics, showing a decline, and from research surveys, showing an increase, have not yet been clarified. However, it may be that changes in the distribution, of which the research surveys only get a snap-shot, are responsible for this apparent conflict.

Using hydroacoustic technology in cage experi-

ments, measurements of the target strength (TS) of chokka squid were continued with a view to apply this methodology routinely for stock assessment purposes. Data collected from a further 14 squid boosted the overall dataset to 45 chokka in which this highly "stochastic" parameter has been measured successfully *in situ*. Whereas the reflected acoustic intensity is approximately proportional to squid length (Fig. 11a), it is proportional to the square root of squid mass (Fig. 11b). It follows that, in squid, mass is proportional to length-squared. Aspects that deserve further research include elimination and correction of errors, analysis and interpretation of variability, and the use of TS data in estimating the biomass of squid spawning concentrations.

Research on squid maturity culminated in a detailed study of oocyte atresia, the first of its kind in cephalopods. Atresia involves degenera-

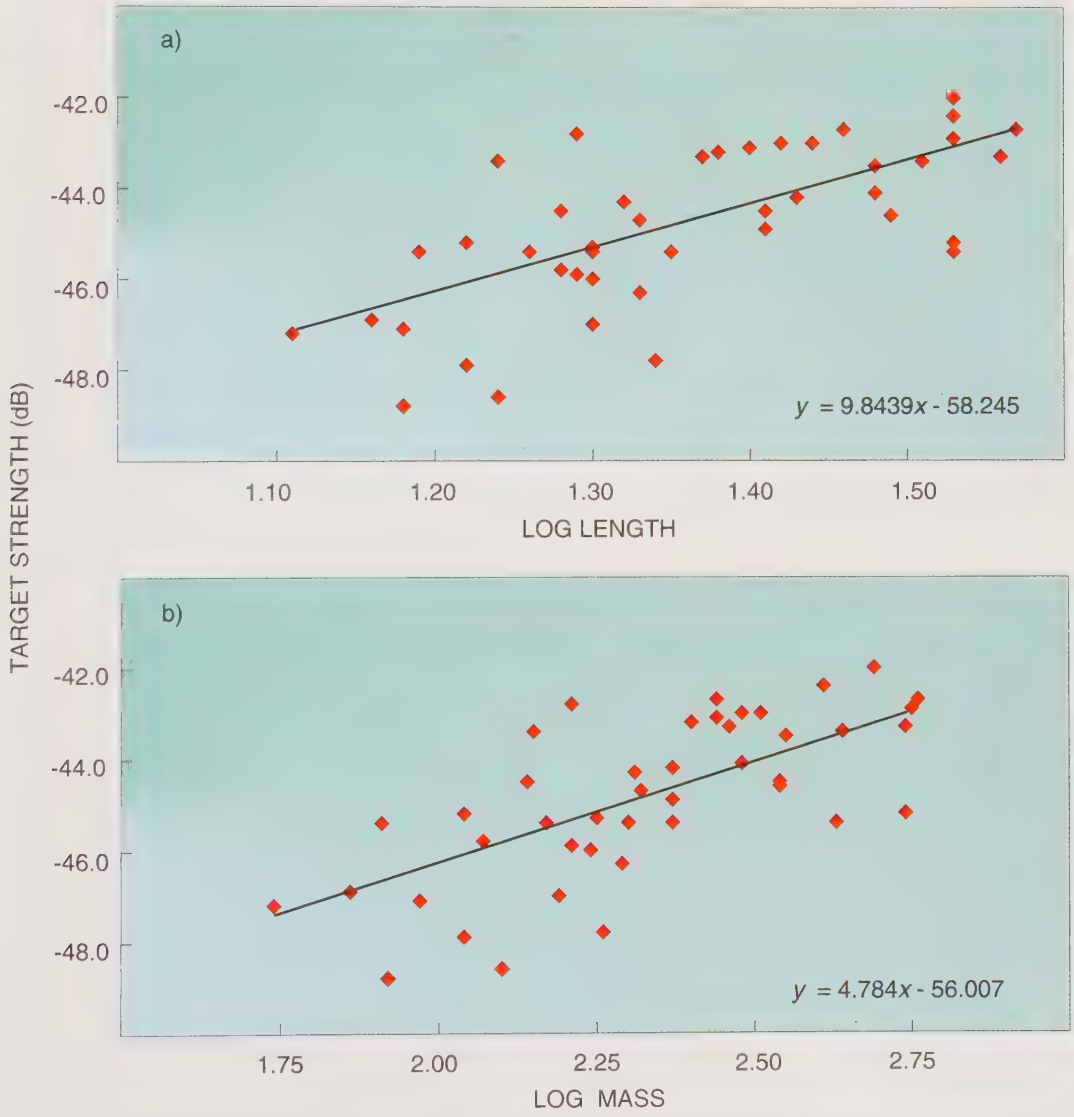

Fig. 11: Target strength of caged chokka squid in relation to (a) mantle length and (b) body mass; regression equations highlight the difference in slope

tion and resorption of oocytes (Fig. 12), processes which are important not only in the reproductive cycle of squid, but also in determining the reproductive capability of the population on the spawning grounds. A histological examination of the ovaries across different stages of maturity showed that the incidence of atretic oocytes within a spawning concentration increased from 15–30% during the peak spawning season to 50–60% later in the season. Such high incidence of atresia marks the end of spawning, with most animals being spent. In terms of estimating reproductive capability in squid, atresia certainly lowers the number of maturing eggs in the ovaries, so decreasing effective fecundity. An important implication of this study is that previous calculations of fecundity in cephalopods may have been too high. Further research in this field is aimed at estimating the duration of each atresia stage in relation to

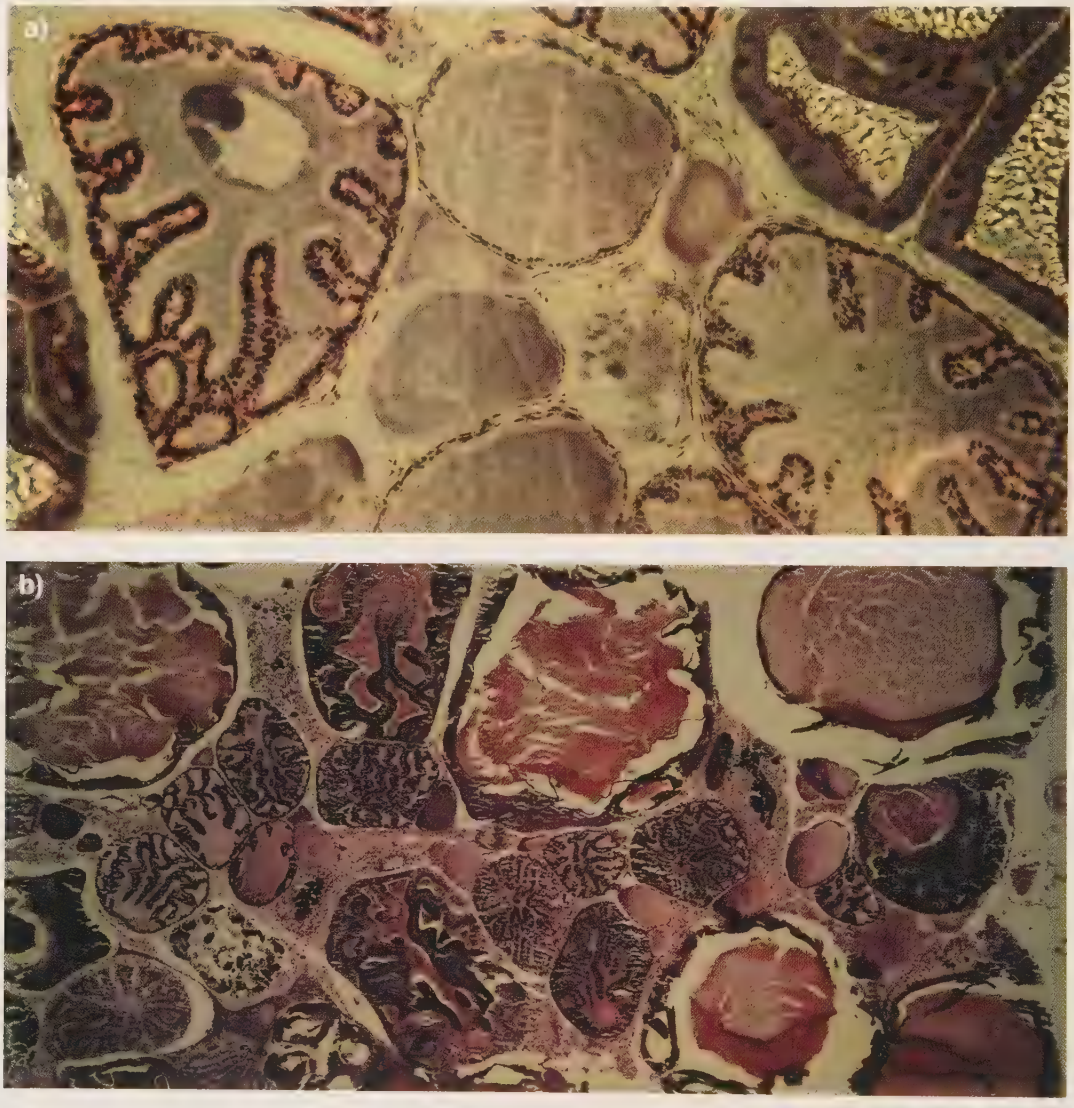

Fig. 12: Section of an ovary of chokka squid showing (a) normal oocytes and (b) atretic oocytes at different stages of degeneration

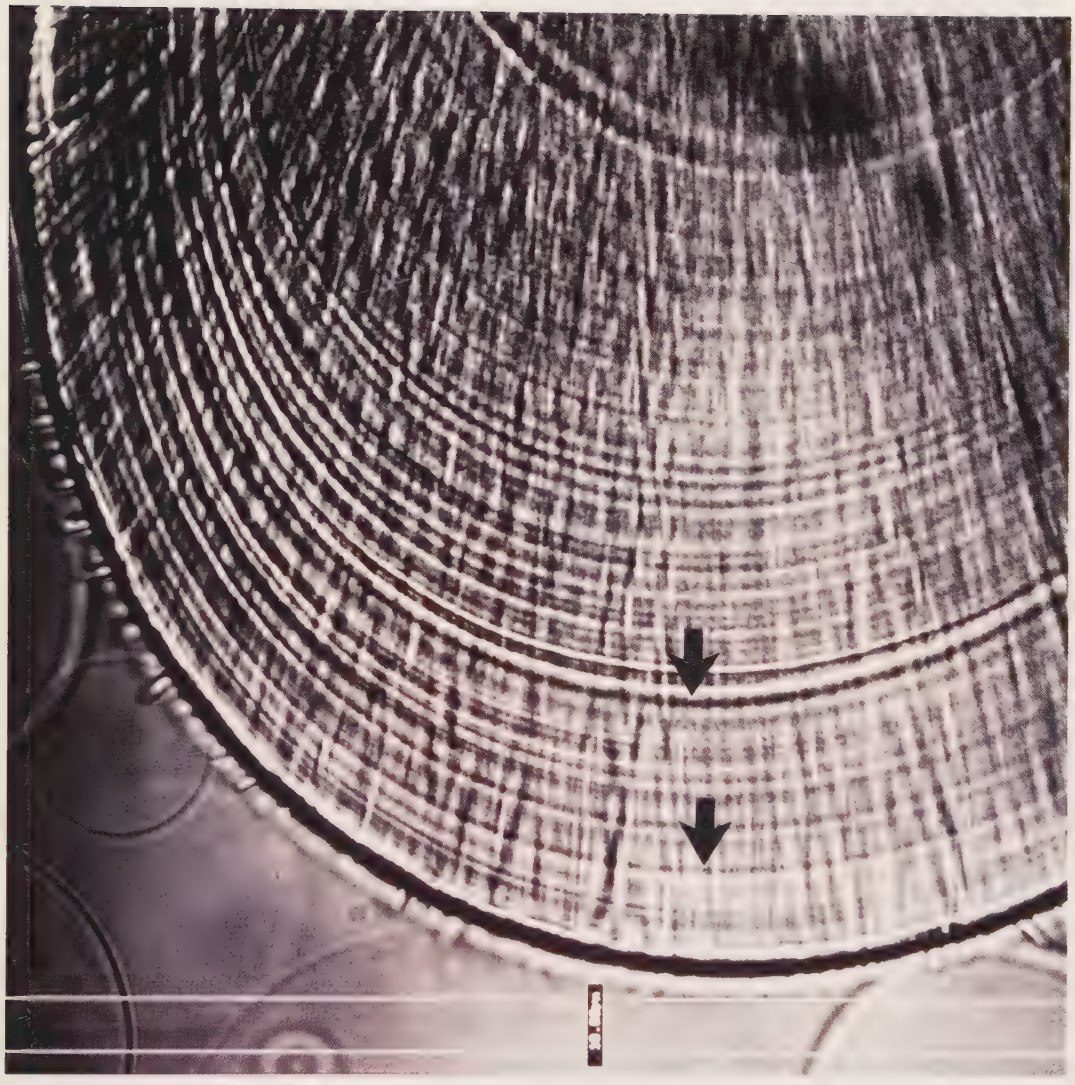

Fig. 13: Section of a loliginid statolith – arrows indicate checks associated with capture (top arrow) and temperature fluctuations (bottom arrow)

the total spawning period, to correct fecundity estimates for losses arising from atresia.

Research on age and growth focused on the increment recognition problem associated with the determination of squid using statoliths. Whereas growth increments are usually deposited daily in the statolith, other, very similar, non-daily structures are also visible, but these cannot easily be discerned from the daily increments. One of the research goals is therefore to identify criteria in order to distinguish daily from non-daily structures unambiguously. To that extent, confocal microscopy, which enhances increment definition, was used to observe and analyse patterns of rings and growth increments in statoliths extracted from loliginid squid (*Loliguncula brevis* from the Gulf of Mexico) kept in aquaria under different temperature regimes (Fig. 13). As the number of days between transfers to different aquaria is known, daily increments can easily be discriminated from any other

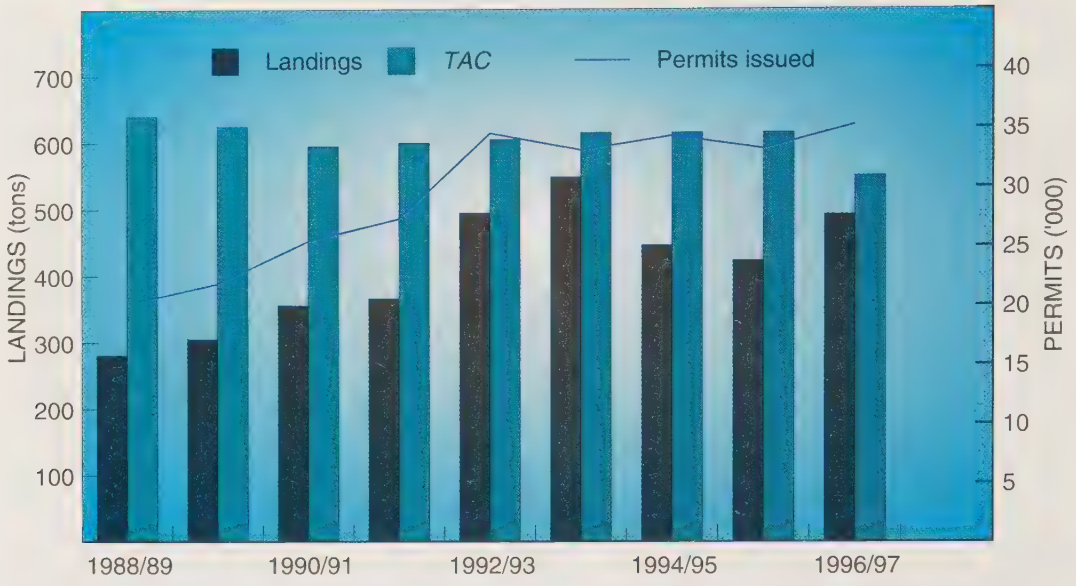

Fig. 14: Time-series of sales of permits to recreational divers, recreational abalone landings as estimated from telephone surveys, and commercial TAC, *1988–1997*

structures. The results of this work now allow increment patterns observed in squid statoliths to be linked to temperature changes experienced in their natural environment.

The first phase of the South African Climate Change and Squid Programme (SACCSP), which seeks a forecasting capability for the chokka squid fishery, was completed during 1997. Results show that spawning by chokka is not restricted to the inshore waters of the Eastern Cape, but also takes place on the adjacent mid-shelf in depths of up to 120 m. So far, SACCSP has culminated in an elaborate conceptual model in which the maturation process of the squid drives its distribution and abundance. The influence of factors such as temperature, turbidity and bottom wave surge on spawning behaviour *per se* remains to be determined, whereas squid behaviour needs to be quantified. For this purpose, a unique, solar-powered buoy system has been designed, manufactured and deployed. While environmental parameters are monitored, an array of four underwater video cameras records squid spawning activity on the sea bed. In addition, micro-acoustic transmitters inserted into the body of selected squid allow their position to be monitored. This information is especially valuable under highly turbid conditions when the use of cameras becomes pointless. All data so collected are telemetered from the buoy at sea to a land-based receiving station, and archived until subsequent analysis. By counting, for example, the number of eggs laid per unit of time and by recording the time spent by squid near and away from the egg bed, a quantitative estimate of spawning squid can be made.

Abalone

Since their inception in 1995, the fishery-independent diving surveys have developed into an intensive monitoring programme of abalone *Haliotis midae*. Throughout the year, whenever sea conditions are calm enough to allow diving in the inshore zone, the state of the resource is assessed both on the abalone fishing grounds and within protected areas. As yet, the short time-series precludes any rigorous statistical evaluation of the data obtained, nor can it

provide a reliable index of abalone abundance. However, one striking observation made over the years is the progressive "desertification" of the Mudge Point area near Hawston, which is known to have been heavily poached for years. Especially the inshore zone has, because of its easy accessibility to shore-based poachers, now become denuded of abalone.

Four major factors influence abalone population dynamics in South Africa. These are commercial exploitation, recreational fishing, poaching, and unusually high mortality of recently recruited juveniles, the latter being a result of increased predation by West Coast rock lobster *Jasus lalandii* on sea urchins which provide shelter for the recruits. The last two factors have elicited particular interest, because it seems that no other abalone fishery in the world is exposed to such a combination of factors affecting the resource negatively. Perhaps the Californian fishery comes closest, with its long history of intense but poorly controlled commercial fishing, predation by an increasing sea otter *Enhydra lutris* population, and a recent apparent increase in poaching. The fact that the Californian fishery was recently closed to all commercial exploitation, and that a once abundant species now faces probable extinction in the wild, should serve as a warning to South Africans.

The recreational fishery continues to be monitored by both telephone surveys and direct field observations. The 1996/97 season produced the highest landings yet, estimated at 492 tons, from 35 200 diver permit-holders, but the trend in catches over the past five years has been a fluctuating one, in contrast to the increasing trend noted for the first five years of the study (Fig. 14). Nonetheless, recreational landings are still higher than historic levels, which are estimated to have been less than 300 tons before the mid 1980s. As present total landings are probably unsustainable, the recreational fishing season was reduced, once again, to four months, from 16 December to Easter Monday (13 April in 1998).

The scale of poaching is escalating, with the total

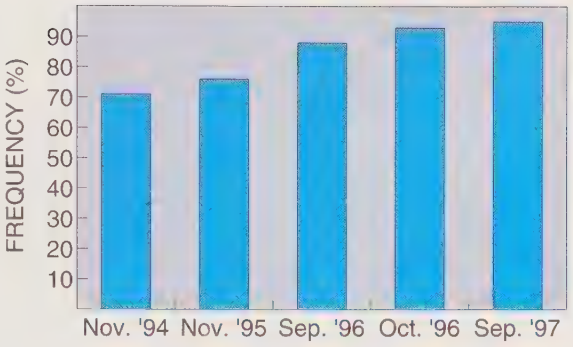

Fig. 15: Increasing frequency of undersize abalone in samples taken from hauls confiscated on site in the Hawston area since 1994

volume of illegal hauls probably being as large as the commercial or recreational take, so posing a serious threat to the future of the resource. Two new trends are of particular concern: average sizes taken by poachers are becoming smaller (Fig. 15), and their area of operation is expanding. A sample taken from a haul of 4 092 abalone confiscated from the Hawston community at the end of 1997 illustrates a blatant disregard for size limits. About 90% of the sample consisted of undersize animals (Fig. 16), with the most abundant size-class being only 3-year-olds (the age-at-100%-maturity is approximately 7 years!). The likely reason for this appalling situation of progressively smaller abalone being targeted by poachers is that the areas most easily accessible to them (as shore-based divers) have already been denuded of large abalone. Considering that abalone recruit naturally in the shallow, inshore zone, and that it is those individuals which are now being systematically decimated by poachers, the scope for population growth is shrinking. Given this scenario, the future of the abalone fishery looks bleak.

During 1997, substantial progress in the management of the West Coast rock lobster fishery was made with the introduction of an OMP replacing conventional size-based analyses. Assessments of the resource had shown it to be

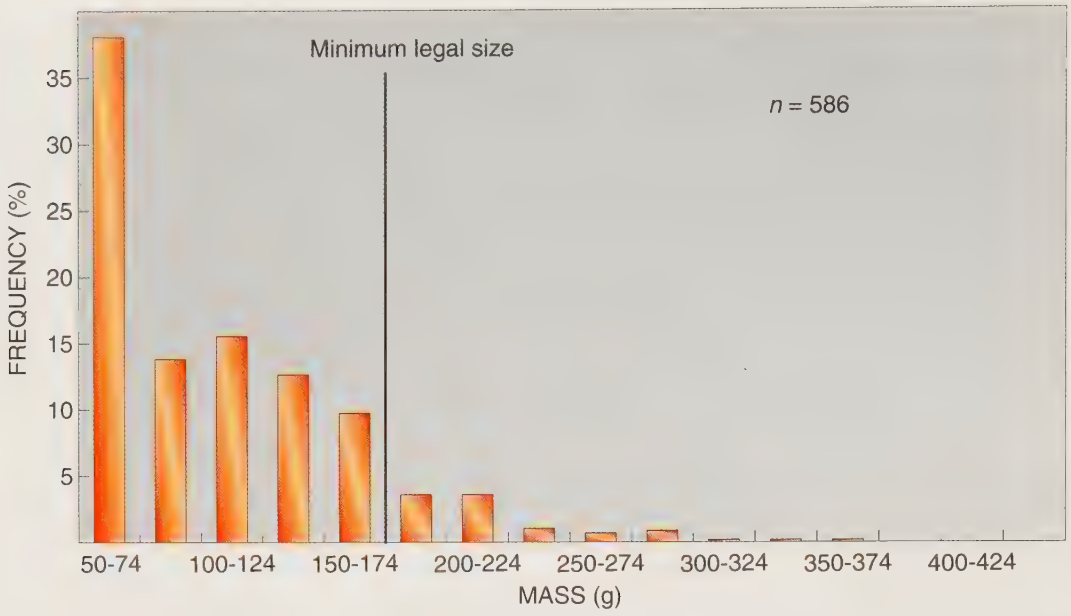

Fig. 16: Size distribution of a sample of an abalone haul confiscated from the Hawston area

seriously depleted, with estimates of recruitment over recent decades only some 35% of pristine. The situation was exacerbated by several years of below-average somatic growth rates during the early to mid 1990s, which severely affected resource productivity (Fig. 17). Associated with the concomitant recent decline in stock size is a possible further reduction in recruitment. Although not immediately detectable because of a typical 7-year delay between larval metamorphosis and entry to the population sampled by the Fishery Independent Monitoring Survey (FIMS), such decrease in recruitment may have serious implications for sustaining the resource and the fishery. In order formally to address the implications of such uncertainties, it became essential to evaluate the long-term consequences of *TAC* recommendations over a range of possible scenarios. Ideally, the management approach adopted would ensure robust behaviour in achieving management objectives (regarding, for example, resource-rebuilding targets) within the envisioned range of future scenarios for the resource. To ensure consistency and efficiency, it was important that the methodology be formalized and standardized to achieve optimum use of both the resource and the industrial and scientific infrastructures, and that it be adopted as a long-term strategy. These goals were met by the selected OMP, which has been implemented for an initial period of three years, after which time it will be reviewed.

Essentially, the OMP revolves around a relatively simple mathematical equation, which provides, as output, a *TAC* recommendation. The input data required are the *TAC* from the previous year and three indices of resource status (somatic growth, commercial *cpue* and FIMS *cpue)* averaged over the three most recent seasons, which were used previously in the size-based model. The equation is such that, if one of the indices increases, it will tend to adjust the advocated *TAC* upwards, whereas a decrease in any index will have the opposite effect. Furthermore, having been tested across a wide range of scenarios regarding the current knowledge of the resource and its use, the OMP displayed appropriate levels of resilience in achieving management goals. Of these, accomplishing a 20% increase in resource biomass (relative to the level estimated for 1996) over 10 years was the most important.

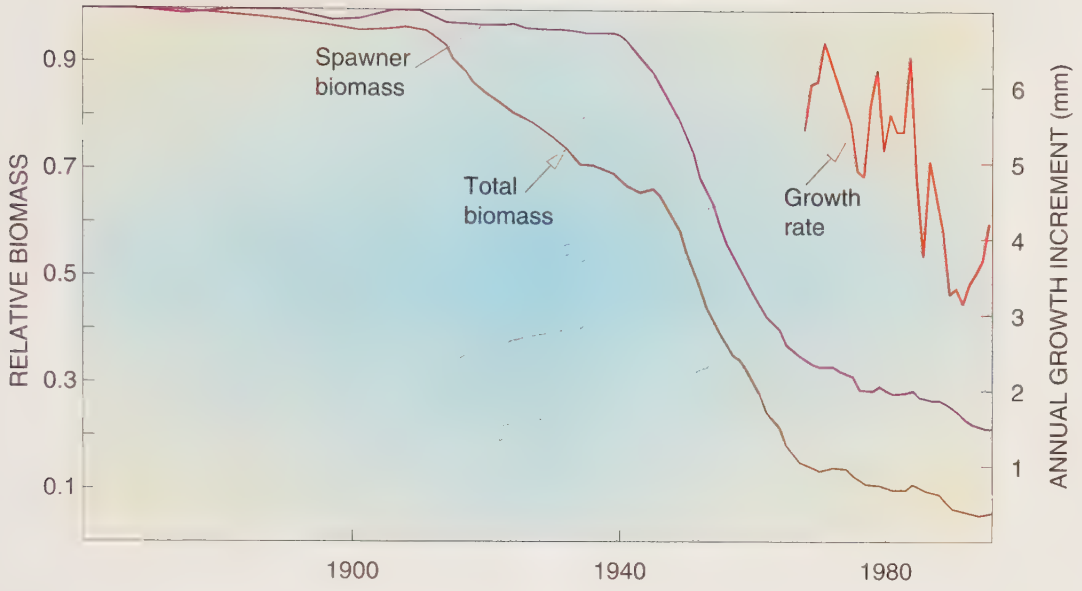

Fig. 17: Trends in spawner and total biomass of West Coast rock lobster, expressed in relative terms and deduced from the size-based assessment model, and recent annual growth increments (carapace length CL*) of a standardized 70-mm* CL *animal*

There is presently insufficient information available to assess the performance of the West Coast rock lobster resource over the 1997/98 season completely. However, monitoring surveys and preliminary analysis of FIMS data have provided clear indications of the impact of the lobster "walkouts" at Elands Bay and surrounds during April and May 1997. They suggest a drastic reduction in the abundance of lobsters on traditional trap-fishing grounds, represented by reefs in water deeper than 15 m. Nevertheless, the fishing industry was comfortably able to land their assigned quota in that area, using hoopnets deployed from dinghies in water shallower than 10 m. More details on the 1997 "walkouts" and their aftermath are given elsewhere in this *Research Highlights*.

Reports from commercial fishers operating in other areas suggest that the modest upward trend in the resource over the past few years is continuing with only one exception, Zone C (the area surrounding Cape Columbine. This area was devastated by a "black tide" during March 1994, which killed not only a large number of lobsters, but also decimated the filter-feeding macrobenthos on which the animals rely for food. Recovery in this area is expected to require at least another two years.

Continued surveys of lobster east of Cape Hangklip have illustrated the importance of an in-depth understanding of the biological processes underlying the dynamics of a resource. Overall trends in the population distribution have remained similar to those described on the basis of exploratory samples, with a tendency for lobster abundance to increase from east to west, but with average animal size increasing in the opposite direction (see Fig. 33). However, there has been a marked change in the demography of the resource, from a male-dominated population early in the year to a female dominance later in the year. This may be caused either by heavy fishing pressure by the recreational sector on the larger males, or by differential inshore-offshore migration patterns of male and female lobsters. Further monitoring will be required to resolve these issues.

Experiments are currently underway to assess

the efficiency of commercial lobster traps with a built-in escape grid instead of the conventional polyethylene mesh collecting bag. The philosophy behind the introduction of this gear was to improve on the size selectivity of traps, so allowing undersize lobsters to escape between the grid bars while the traps are deployed. This would drastically reduce the number of undersize lobsters brought to the surface, so decreasing the rate of incidental mortality among lobsters not yet recruited to the fishery. Preliminary results are somewhat inconclusive, primarily owing to the high variance in catch rates. However, there are indications that the experimental traps may be less efficient than anticipated. Despite releasing undersize individuals effectively, catches of legal-sized lobsters also appear to be drastically curtailed by these traps, possibly as a result of increased escapement through the side mesh during retrieval of the traps.

Several new research projects will be initiated or expanded during 1998. Among the most important are: post-larval recruitment surveys, which could prove extremely valuable in providing long-term forecasts of resource health; the determination of juvenile growth rates, which will describe the rate at which post-larval recruitment is translated into harvestable biomass; the assessment of lobster resources in sanctuary areas, which should illustrate the importance of reserve areas to the management of the resource; an investigation into factors influencing lobster catchability, which should help in understanding patterns in *cpue* time-series; and the testing of new tagging methodology, which should aid both in the estimation of rates of tag loss and the identification of conventionally tagged lobsters which have not moulted during the expected time.

Seaweed

Cultivation of the agar-producing seaweed *Gracilaria gracilis* at Small Bay, Saldanha, has been the subject of considerable research for a number of years. Previous research revealed that summer conditions of warm, nutrient-depleted surface waters following prolonged southerly winds have a deleterious effect on the growth of *Gracilaria*. At the same time, the discharge near the fishing harbour of fish waste into Small Bay may supply nitrogen to the system.

A 1-year project during 1996/97 therefore examined whether *Gracilaria* would grow better at a site 1 km downstream of the waste outfall of the pelagic fish factory than at a control site about 3.5 km away, in the north-east corner of Small Bay. Results showed a spectacular difference in growth rate in October–December, when all *Gracilaria* at the control site died as surface nutrients levels dropped, whereas above-average growth of 8–10%·day^{-1} was evident at the fish-waste sites. Growth of *Gracilaria* at the control site improved during the period December–February, and eventually caught up with that near the fish-waste outfall in winter as the water column progressively destratified and nutrient levels at the surface rose with the mixing of upwelled water from below the thermocline. Interestingly, a concomitant university study, using a nitrogen isotope-ratio technique, showed that the fish waste-derived nitrogen is well distributed throughout northern Small Bay, in sediments and in the benthic *Gracilaria* populations. In fact, at certain times there can be more fish-derived nitrogen in *Gracilaria* cultivated at the control site than downstream of the fish-waste outfall. It is therefore clear that this nitrogen source could play an important role in the mariculture of *Gracilaria* in Small Bay. It is estimated that, based on an approximate 3% nitrogen content of this seaweed, a 40-hectare farm would remove about 43 tons of nitrogen from the bay per year, much of which would be derived from the estimated 650 tons of fish-waste nitrogen discharged into the water.

With growing interest in establishing commercial cultivation of *Gracilaria* in St Helena Bay, the first experiments to assess the suitability of this area for seaweed mariculture were started in 1997, in conjunction with university students. A small test system for suspended cultivation of this red seaweed was placed in the water at

Vioolbaai in July. So far, *Gracilaria* has been found to grow better in St Helena Bay than in Saldanha Bay during a simultaneous, comparative experiment, showing on average a 1%·day^{-1} higher mass increase. This superior growth rate is expected to be attributable to the incidence of higher nutrient levels in St Helena Bay. The only problem encountered so far is that of drifting kelp mats in winter, damaging the cultivation system, but which can be overcome simply by removal of the kelp by hand. Most of this project revolves around a study comparing growth rates and agar contents of *Gracilaria* isolates ("strains") from St Helena Bay, Saldanha Bay and Langebaan Lagoon. The findings of that university-based study will be of direct benefit to future entrepreneurs who wish to venture out on this low-tech, labour-intensive mariculture activity.

Increased demands for fresh kelp fronds as abalone feed have led to kelp-harvesting experiments on several parts of the coast. Results have shown that recovery after the cutting of whole plants can be slow in areas where there are numerous benthic grazers such as sea urchins and herbivorous snails. This is because kelp, in order to produce another large plant (sporophyte), has to pass through all its life history stages, the smallest of which are very susceptible to grazing mortality. The possible advantages of cutting only the fronds was therefore assessed experimentally in *Ecklonia maxima*. Cutting the strap-like lateral sporophylls (fronds) that grow out of the spear-shaped primary blade 30 cm from their origin where the meristem (growing point) lies resulted in significantly greater re-growth than if the cut was made 10 or 20 cm from the meristem (Fig. 18a). If the fronds were cut off 2 cm from the meristem, the latter was damaged and the whole plant died. Examination of different harvesting intervals (Fig. 18b) showed that monthly harvesting reduced growth significantly, whereas intervals of 2, 3 or 4 months produced less marked effects. A maximum annual yield of 3 795 g·plant^{-1}·year^{-1} was achieved by harvesting at 2-monthly intervals, whereas a maximum yield per effort (*cpue*) of 1 089 g·plant^{-1}·harvest^{-1} was obtained by harvesting every four months (Fig. 18c).

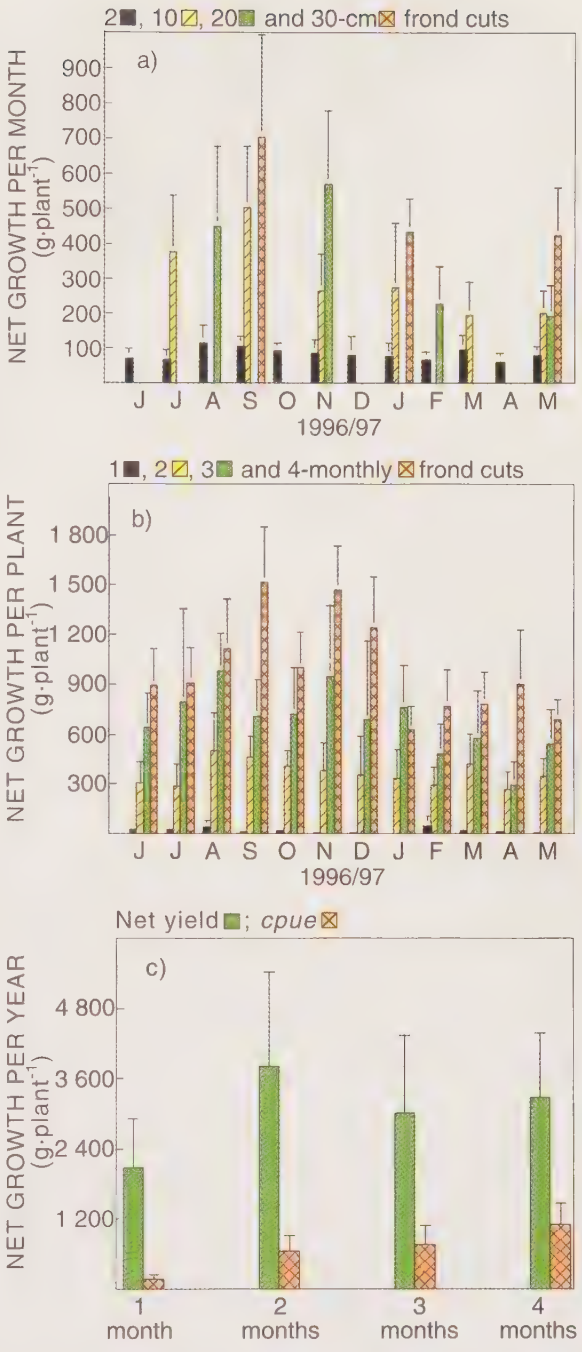

Fig. 18: Net growth (+95% confidence interval) of Ecklonia maxima *fronds harvested at (a) different distances from the meristem and (b) different time intervals, and (c) net annual growth v. harvest* cpue *of fronds harvested at these time intervals*

The harvesting of *Ecklonia* fronds, by cutting 30 cm from the base every four months, is now an experimentally established option that ensures sustainability, even in kelp beds where benthic grazers are abundant. However, whether cutting of fronds only, rather than whole plants, is a practical and economically viable strategy remains to be investigated. It is likely that harvesting applications will have to be dealt with on a site-specific basis. Various options are possible, ranging from frond-only, through mixed, to whole-plant cutting, depending on the ecology of the particular kelp bed.

HIGHLIGHTS OF SUPPORTING RESEARCH

Water masses in the Angola-Benguela front region

Antarctic Intermediate Water (AIW) is identified in the oceanic water mass by the presence of a salinity minimum. It is formed in the subantarctic zone of the Southern Ocean, in the region of the Polar Front, where cold water sinks and moves northwards into the ocean gyres. The low-salinity signature is introduced in this formation region by precipitation exceeding evaporation. Previous studies have shown that the AIW north of the Angola-Benguela front reaches that position by circulating through the western basins of the South Atlantic and through the equatorial current complex, whereas the AIW south of the front arrives through the Cape Basin.

During April 1997, scientists from Norway, South Africa, Namibia and Angola conducted a research cruise between Walvis Bay and Luanda to investigate physical-biological processes in the Angola-Benguela front region and the parent water masses. This cruise, on board the R.V. *Dr Fridtjof Nansen*, followed the official launching of the BENEFIT programme (see section on International involvement), and provided the basis of a number of research projects for Angolan and Namibian students.

The presence of the AIW in the Angola-Benguela front region was identified from CTD profiles extending below the depth of the salinity minimum layer. Extraction of data on pressure, temperature, salinity and oxygen at the salinity minimum showed that this layer is situated about 750–850 m deep. The distribution of oxygen at the salinity minimum (Fig. 19) revealed that the front is not only a surface feature, but can also be discerned at much greater depths. In the shelf and slope region close to the continent, the northern AIW water appeared to move southwards. As such, it may provide a source for low-oxygen water which upwells onto the shelf in that region.

Predicting copepod growth in the Benguela

Copepods are the most plentiful multicellular animals on earth, outnumbering the insects, which have more species but fewer individuals. In the estimated 1 370 million cubic kilometres of world oceans and seas, these microscopic crustaceans form the major component of the marine zooplankton. Owing to their sheer numbers, they play an important role in marine foodwebs, providing a food source for most fish during at least some part of their life cycle. Fish can therefore be regarded as a type of census-taker of the number of copepods. For example, almost 60 000 calanoid copepods were found in the stomach of one herring from the Murmansk area.

Not only are copepods superabundant, but they also grow at an appreciably rapid rate. The prodigious fecundity of copepods was recognized more than 100 years ago, with estimates of 4.5 billion individuals produced in one season from one female through four generations. More recently, it has been estimated that there are nine billion copepods produced annually in a volume of 10 m^3 of seawater in the Baltic Sea. By measuring copepod growth rates, it is possible to determine, *inter alia*, seasonal and interannual differences in the quantity of food produced that is available to pelagic fish. This may, for instance, explain differences in the number of fish recruiting to the fishery each year.

A problem associated with measuring copepod growth in the field is that the techniques used are very labour-intensive and expensive.

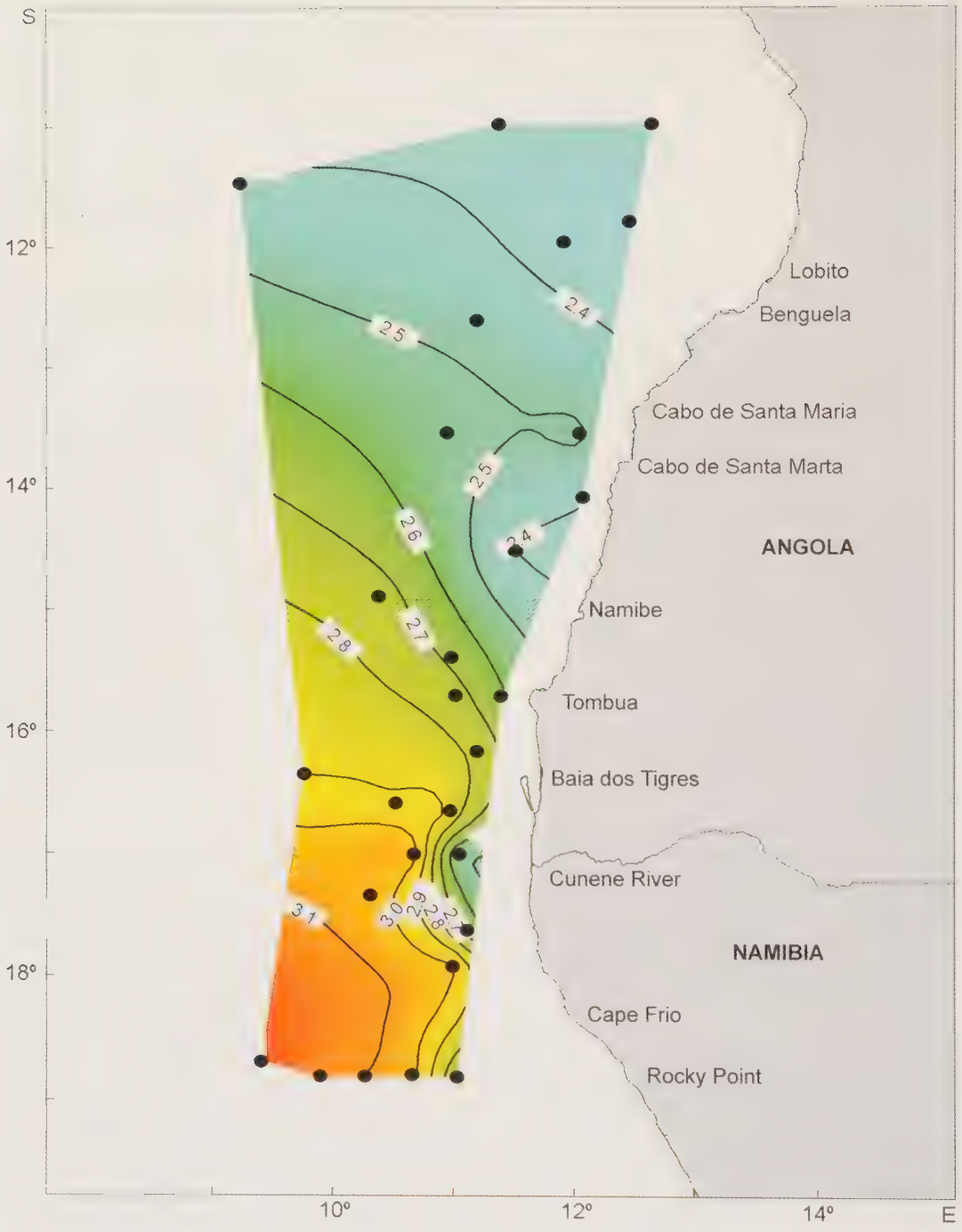

Fig. 19: Distribution of oxygen concentration (mℓ·ℓ⁻¹) at the depth of the salinity minimum in the region of the Angola-Benguela front during April 1997

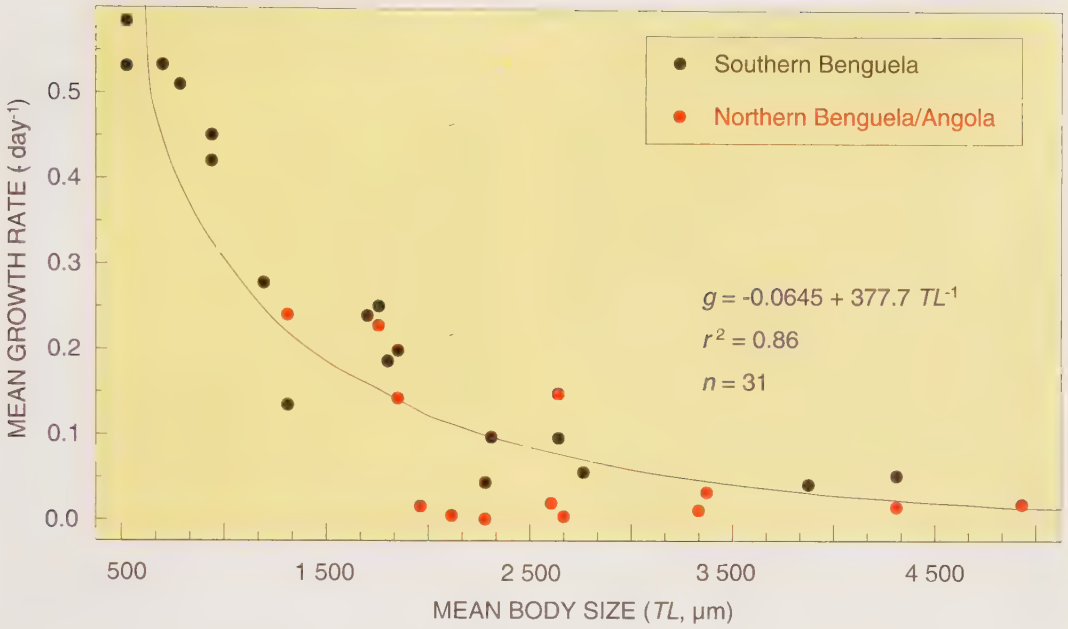

Fig. 20: Daily growth rates (g) of juvenile and adult calanoid copepods from the northern and southern Benguela in relation to body size (total length TL*)*

Analysis of more than 3 500 *in situ* experiments conducted in the Benguela over the past 10 years has shown that it may not always be necessary to measure growth rates of copepods at sea to obtain an estimate of their production. A strong inverse relationship has been found between daily growth rate of calanoid copepods and their body size (Fig. 20). Moreover, not only does this relationship hold over a broad range of copepod body sizes (500–5 000 µm total length), but it also seems to be valid in both the southern (South Africa) and the northern (Namibia) Benguela systems. Besides allometric considerations, this relationship suggests that food is limited in a body-size dependent manner under natural conditions, with larger copepods being more food limited.

Application of this relationship may therefore save considerable effort in estimating copepod growth rates at sea. Future work will incorporate this relationship in estimating the production, derived from growth rate multiplied by biomass, of the entire copepod community, based on accurate measurements of copepod biomass and a knowledge of their size distribution. This approach will provide a reasonable estimate of the quantity of food available to fish.

Transport of upwelled water off Cape Columbine

For decades, lighthouse-keepers have been monitoring winds along the South African coast using an instrument consisting of a plate and damper for speed, and a wind vane for direction. Although the instrument was simple, the dedication shown by the lighthouse keepers has been in the finest maritime traditions. Indeed, comparisons with data from automatic weather stations, which ran intermittently from 1984 onwards, gave good agreement and consequently the lighthouse-keeper wind data are deemed to form a valuable scientific dataset.

From a nearly continuous time-series of hourly wind kept at Cape Columbine lighthouse between 1957 and 1991, when measurements

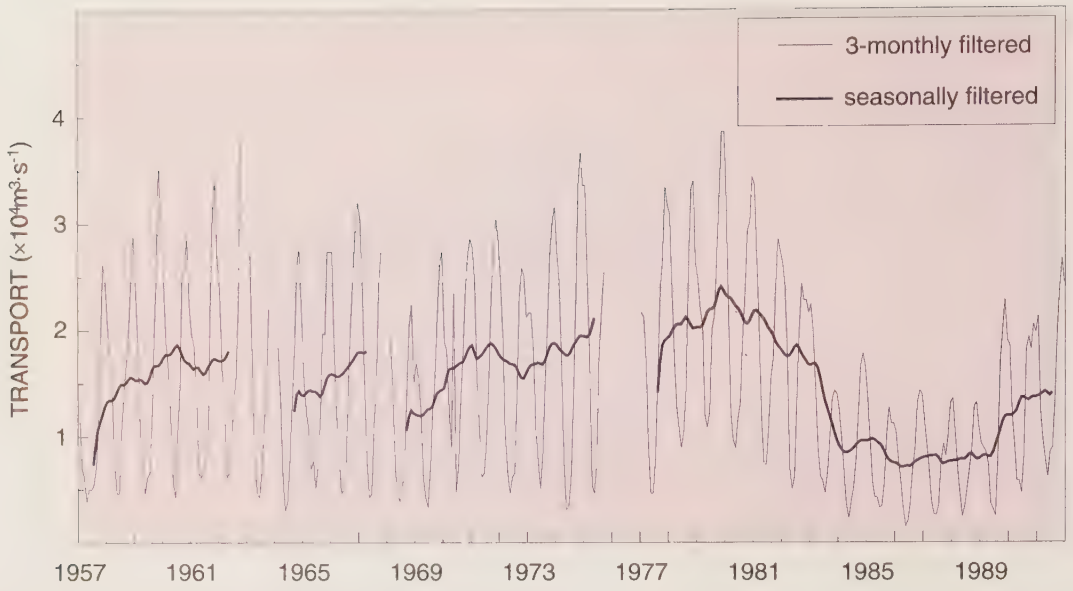

Fig. 21: Time-series of Ekman-layer transport for the Cape Columbine upwelling cell, 1957–1991

were discontinued, the longshore component was extracted and a simple model applied to calculate the relative rate of upwelling for the Columbine cell over this period. The model is based on a balance between the forces produced by the rotation of the earth and the frictional forces caused by the wind. The wind creates a turbulent surface layer some 50 m thick in which the upwelled water moves away from the coast to form a tongue. Satellite images show that the baseline of this tongue is 30 km long. Using this information and well-researched estimates of wind drag, it is possible to calculate the total volume of upwelled water transported during the upwelling process.

The time-series was filtered to remove the effect of the diurnal land-sea breeze and other short-term processes operating on a scale of a few days. This left a marked seasonal cycle of water transported which, as can be seen in Figure 21, displayed large swings of 2 500–40 000 $m^3 \cdot s^{-1}$ from winter to summer. The period 1983–1988 shows a distinct pattern of weaker wind, which is best seen in the seasonally-filtered data also displayed in the figure. Whereas the annual time-series mean was about 15 000 $m^3 \cdot s^{-1}$ prior to 1983, it remained at 7 500 $m^3 \cdot s^{-1}$ over the period 1983–1988, recovering in 1989.

Wind strength is related to the high pressure cell over the south Atlantic, and the cause of its modulation may be found as far afield as the Antarctic. Pressure and winds over the mid-latitudes of oceans of the southern hemisphere changed appreciably after the late 1970s, in relation to lower pressure in the Antarctic region and a stronger polar vortex. This pattern persisted for nearly a decade. Such changes are currently being researched intensively among meteorologists.

The incidence of Diarrhetic Shellfish Poisoning on South Africa's West Coast

Gastrointestinal illness associated with the consumption of mussels exposed to dinoflagellates was first diagnosed in the Netherlands in the 1960s. The poisoning was given the name Diarrhetic Shellfish Poisoning (DSP), because the dominating symptoms are diarrhoea, nausea,

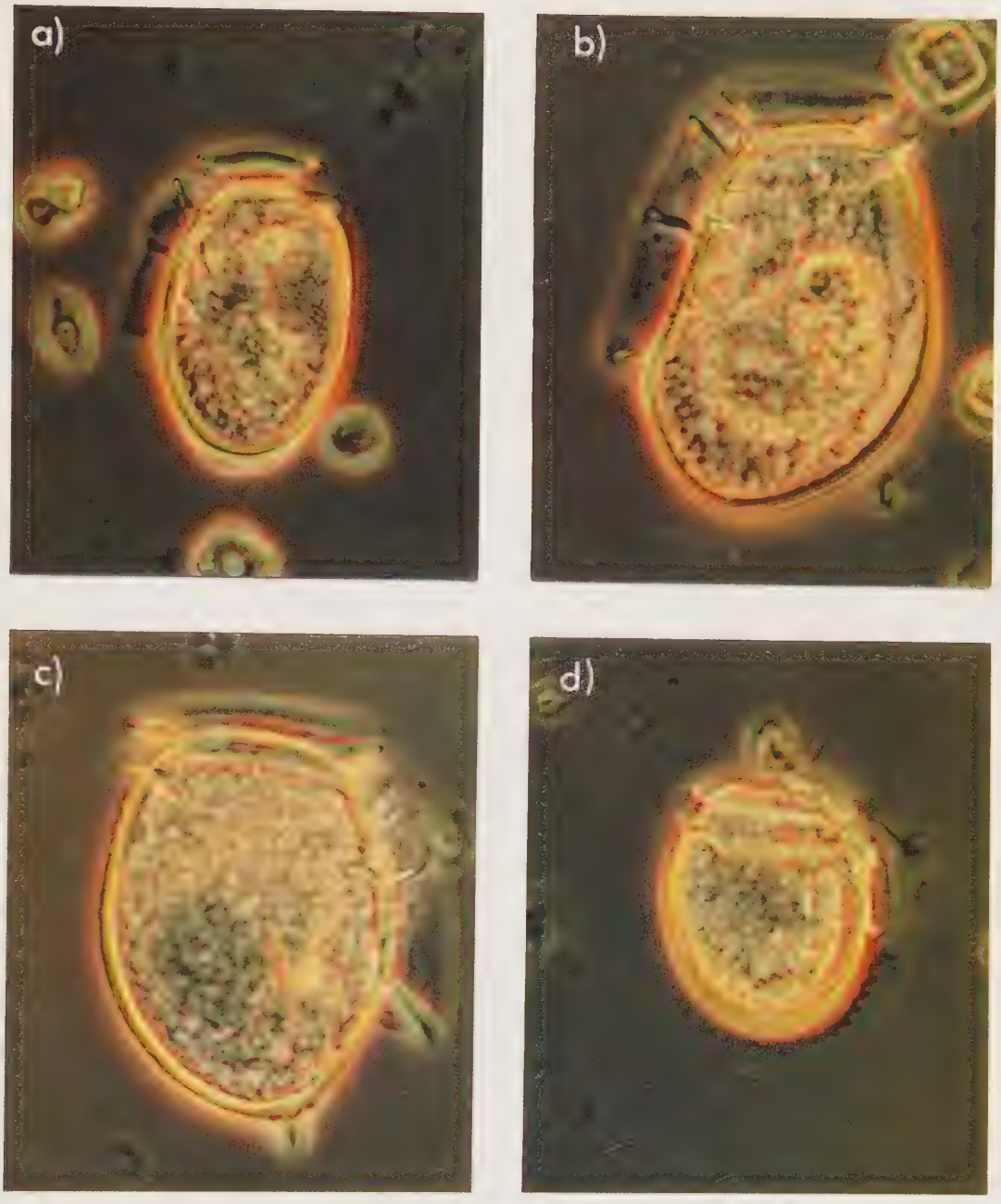

Fig. 22: Dinophysis *species known to be responsible for DSP – (a)* D. acuminata, *(b)* D. fortii, *(c)* D. hastata, *(d)* D. rotundata *(G. C. Pitcher/D. Calder, SFRI)*

vomiting and abdominal pains. Subsequent studies have shown that the DSP syndrome is triggered by certain dinoflagellates, mostly from the genus *Dinophysis*. DSP was first identified on the South African coast in 1991 and attributed to the dinoflagellate *Dinophysis acuminata*.

In 1992, a daily phytoplankton sample collection

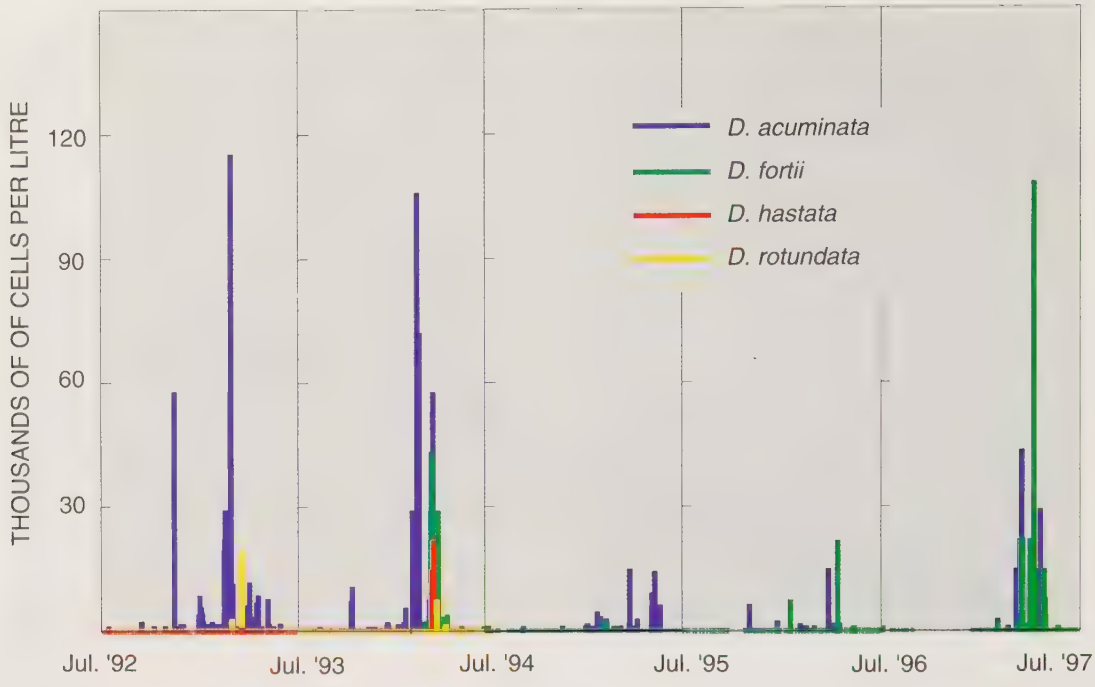

Fig. 23: Time-series of the Dinophysis *species responsible for DSP at Elands Bay, July 1992 – July 1997*

programme was initiated at Elands Bay on the West Coast to monitor harmful algal blooms. This programme has subsequently revealed the presence of four *Dinophysis* species on the West Coast, all of which are known to be responsible for DSP (Fig. 22). The species within this genus are easily recognized. *Dinophysis acuminata* has a more or less oval shape, whereas cells of *D. fortii* have a straight ventral side, but smoothly convex dorsal side and antapical end. *D. hastata* has a conspicuous antapical spine and *D. rotundata* is more or less round, with the epicone visible as a small convex cap above the cingulum.

A time-series of the abundance of these *Dinophysis* species at Elands Bay indicates that they occur intermittently throughout the upwelling months in low concentrations as a component of multi-specific populations (Fig. 23). Despite considerable interannual variation in both the species present and in the cell densities observed, cell concentrations tend to peak in the latter half of each upwelling season.

Black mussels were also collected daily in Elands Bay in 1995 to monitor DSP toxicity levels. Mussel samples were analysed for okadaic acid, one of the toxins responsible for DSP, by means of an ELISA Quick Test Kit. Despite the relatively low concentrations of *Dinophysis* in the plankton during 1995, toxin concentrations in the mussels exceeded the harvestable limits of 2 $\mu g \cdot g^{-1}$ hepatopancreas for a considerable part of the year (Fig. 24). Periods of higher toxin concentrations corresponded reasonably well to periods when *Dinophysis* was prevalent in the plankton, indicating that a concentration of approximately 2 000 cells$\cdot \ell^{-1}$ was sufficiently high to contaminate shellfish.

These results, together with the annual proliferation of *Alexandrium catenella*, the dinoflagellate responsible for Paralytic Shellfish Poisoning, endorse the need for an intensive monitoring programme for harmful algal blooms on the West Coast in order to protect public health.

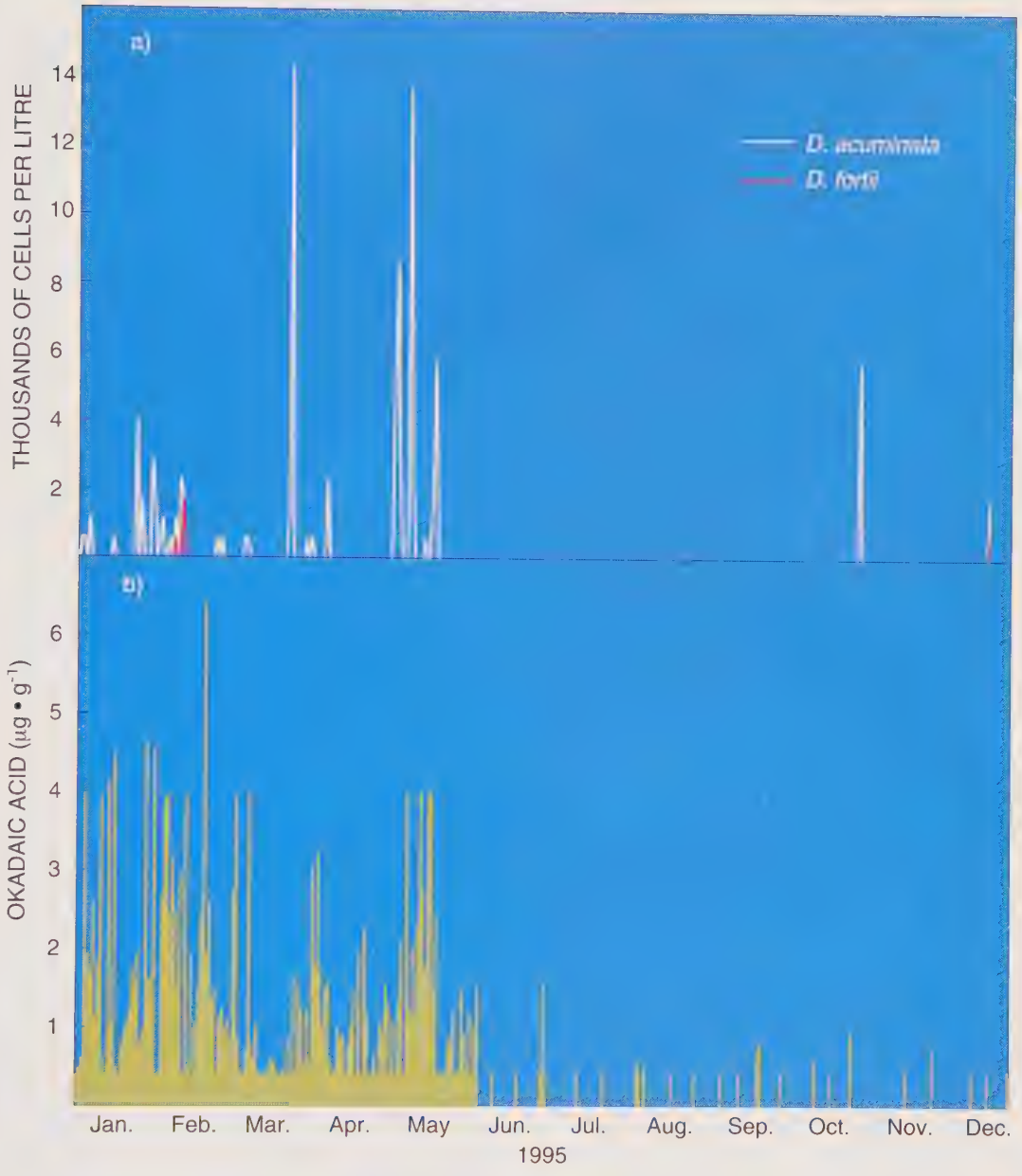

Fig. 24: Time-series of concentrations of (a) Dinophysis *in plankton samples, and (b) okadaic acid in mussels, both collected from Elands Bay during 1995*

Mass strandings of West Coast lobster and their aftermath

During March and April 1997, large numbers of West Coast rock lobster *Jasus lalandii* were stranded on the beaches near Elands Bay (Fig. 25). These events followed the decay of an extensive red tide along the West Coast. Usually, such phytoplankton blooms are fairly rapidly dispersed by wind-driven currents. However, on this occasion, upwelling and bloom formation were followed by an exceptionally long period of

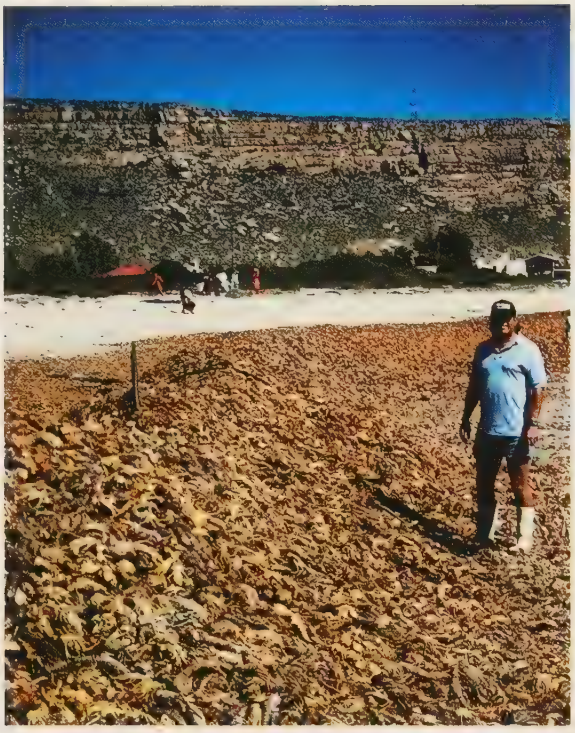

Fig. 25: Mass stranding of West Coast rock lobster at Elands Bay during March/April 1997 (A. C. Cockcroft, SFRI)

calm weather. Bacterial decomposition of the bloom generated extremely low oxygen in the water column. As the water quality deteriorated, increasing numbers of lobsters sought refuge in the shallows of the surf zone, where wave action provided some aeration. Eventually, overcrowding ensued and lobsters stranded on the beaches during low tides, especially during spring tides, when the tidal range was greatest. By early May, more than 2 000 tons of mainly female and undersize lobsters had washed ashore. This exceeded the quota allocated to the Elands Bay area fivefold, and even surpassed the annual *TAC* of 1 700 tons set for the entire industry. Owing to the efforts by industry, the SA Police Services, the Defence Force and Sea Fisheries personnel, roughly half of the stranded lobsters were returned alive to the sea beyond the offshore limits of the red tide. The remainder were either removed by the public, buried on the beach or processed as fishmeal.

Trap and dive surveys conducted immediately after the major strandings indicated the absence of lobsters on the conventional fishing and spawning grounds (Fig. 26a). However, large banks of live lobsters were detected in the shallows (<1.5 m depth) of the surf zone. Analyses of water samples confirmed extreme oxygen-deficiency (<0.35 $m\ell O_2 \cdot \ell^{-1}$) near the bottom beyond the breakers. *J. lalandii* are inclined actively to avoid chronic exposure to water with oxygen levels <2 $m\ell O_2 \cdot \ell^{-1}$, so it is likely that their distribution pattern was driven by oxygen-deficiency. Moreover, the digestive tracts of stranded lobsters were, as expected, devoid of food, as *J. lalandii* stop feeding when under oxygen-stress.

Subsequent systematic trap and dive surveys at Elands Bay during July and September 1997 revealed that the surviving population was concentrated on a moderately deep (30–35 m) reef, roughly 2 miles from the shore, and that there were no lobsters in the shallows (Fig. 26 b–d). Females were scarce (<5%), and many of the males captured had broken appendages. This may have been a result either of being tumbled in the surf zone, or of being beached, collected, transported and dumped at sea. Nevertheless, since the opening of the 1997/98 commercial lobster fishing season in November 1997, large numbers of lobsters have been captured in Elands Bay using hoopnets deployed from dinghies in shallow (<10 m) water. Correspondingly, low catches have been made on traditional trap-fishing grounds in deeper water, suggesting that the lobsters observed in a tight aggregation earlier in the year had migrated into the bay. This hypothesis is supported by preliminary analyses of 1998 FIMS data, which suggest a drastic reduction in the abundance of lobsters in water deeper than 15 m, compared to previous years.

The strandings (colloquially referred to as "walkouts") at Elands Bay during 1997 were by far the worst ever recorded, and their long-term implications for the fishery and ecology of the area have yet to be fully evaluated. The *J. lalandii* resource is relatively slow-growing and long-

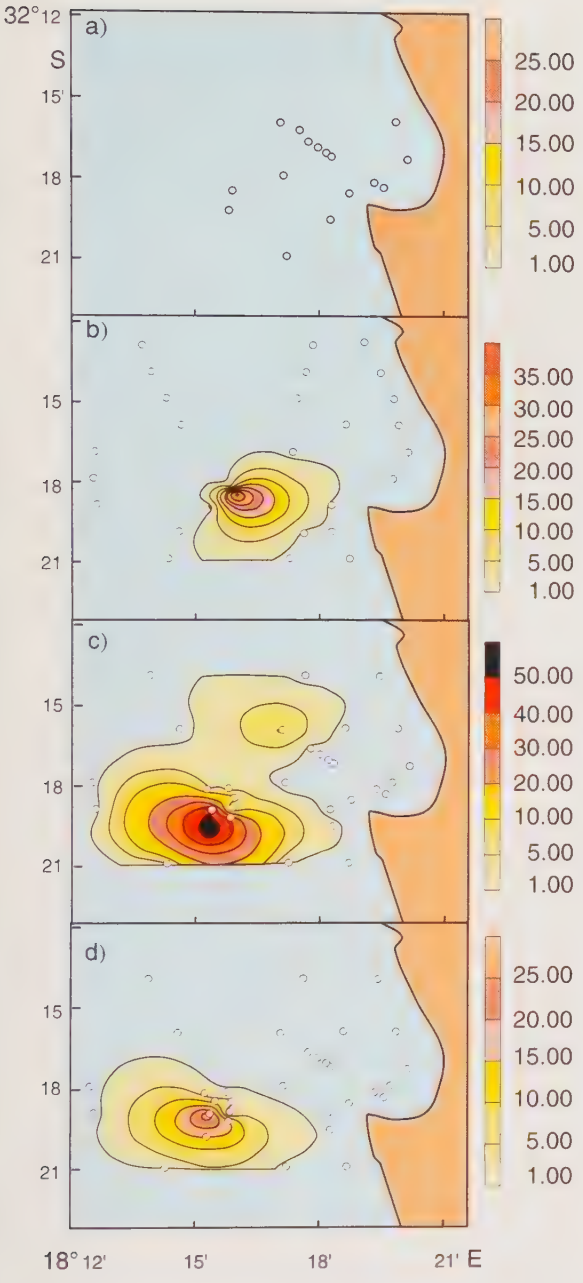

Fig. 26: Catch rates of rock lobster at Elands Bay during and after the April 1997 "walkout" – (a) April 1997 survey (zero catches), (b) July 1997 tag survey (total kg·trap^{-1}·day^{-1}), (c) September 1997 survey (total kg·trap^{-1}·day^{-1}), (d) September 1997 survey (kg legal size·trap^{-1}·day^{-1})

lived, with recruitment to the fished population typically requiring in excess of six years. Therefore, yield to the fishery is dependent on two sources of productivity: somatic growth of fully recruited animals during the annual moult, and recruitment to the fishable population of previously undersize specimens. Many of the lobsters stranded during the event were undersize, so unless extensive immigration takes place, recruitment to the local fishery could be poor over the next few years. Moreover, physical damage to the lobsters themselves, as well as to their macrobenthic food source, may influence local somatic growth negatively. Continued monitoring during 1998 and beyond will provide more insight into some of these important ecological implications and management issues.

Circulation patterns in Saldanha Bay

With plans to develop the mussel industry further in Saldanha Bay, there is much interest in the circulation patterns within the areas where rafts will be placed. Also, the potential for primary production and oxygen supply within the farm depends on the greater circulation of the bay. Between 1990 and 1995, 16 current meters were moored in Saldanha Bay (Fig. 27). Four of these were set by the Institute for Maritime Technology and, with the permission of the Naval Hydrographer, were incorporated into an holistic study of Big Bay, Small Bay, the throat at the causeway and the entrance to the bay.

The most significant observation is that water from the West Coast shelf is forced into the bay in the deeper layers with a period of 4–6 days throughout the year. This corresponds to the passage of shelf waves, generated by the wind. The eastward phase of these waves was seen at one current meter at the mouth of the bay to last 48 h, whereas the westward, or flushing phase, lasted 62 h on average. Therefore, the penetration of cold shelf water into the bay was 4 km at an average speed of 2 km·day^{-1}. This water was found to feed upwelling in the bay, particularly at two sites in Big Bay.

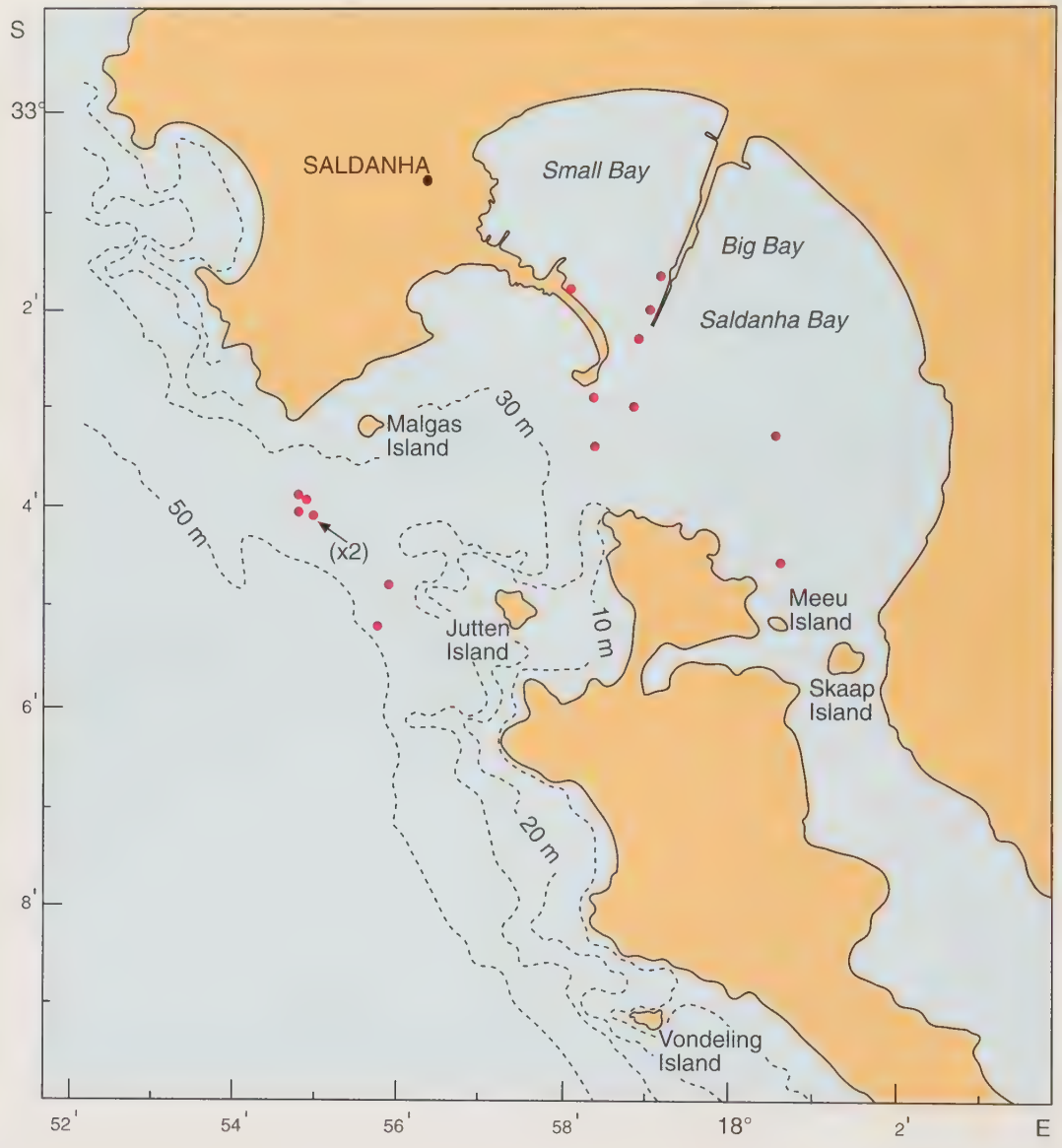

Fig. 27: Positions of the 16 current-meter moorings deployed in Saldanha Bay between 1990 and 1995

When south-easterly winds blow, water is entrained into the upper layers. The shelf waves and wind episodes do not always have a matching phase, and so there is great variation in the intensity of upwelling in the bay. Tides play an important role at the southern end of Big Bay. The flow in and out of Langebaan Lagoon dominates the flow, especially at spring tide.

Impact of mussel culture on the environment

The Spanish mussel *Mytilus galloprovincialis* has been cultured on rafts in Saldanha Bay on the west coast of South Africa since 1984. Annual yields have been in the region of 27 tons wet mass (with shell) per raft, totalling some 1 600

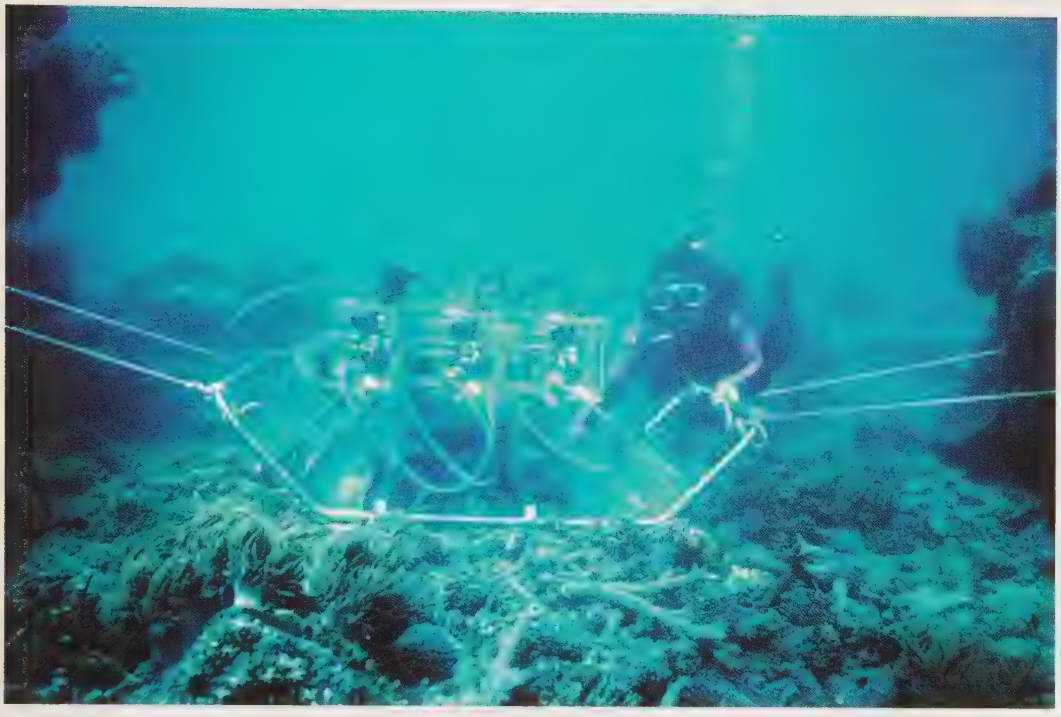

Fig. 28: The benthic data-logging respirometer in situ *(courtesy of Australian Institute of Marine Science)*

tons·year^{-1} from 60 rafts. Besides the mussels, rafts are inhabited by an abundance of fouling organisms, principally the sea squirt *Ciona intestinalis*. The rate of sedimentation resulting from faeces production, dislodged mussels and foulers beneath each raft fluctuates around 300 kg organic carbon·year^{-1}·raft^{-1} and 45 kg nitrogen·year^{-1}·raft^{-1}.

To determine the biological impact of such high sedimentation, samples of benthic macrofauna beneath the rafts were collected annually for four years from 1993. Results from species composition analyses indicated disturbances in benthic community structure, the extent of which varies with age and position of the rafts within the farm. These disturbances reflect excessive organic loading, as supported by measurements within the farm of reduced benthic oxygen fluxes by 60% and up to fivefold increases in organic carbon content in the sediments relative to outside the farm. Such benthic eutrophication, if unchecked, is likely to impact severely on not only the stability of the benthic ecosystem of Saldanha Bay but also on the mussel yield, especially when an intended increase of the lease area from 50 to 1 500 ha is effected.

This study presented a "yes/no" scenario with a distinct affirmation of the impact that mussel farming may have on the environment. In order to understand the ecological processes that are impacted by mussel culture, the project has expanded to study several components of the ecosystem, such as the fauna in the sediments below the rafts, the marine life in the water column and that on the rafts. Two of an anticipated six surveys have been completed in Saldanha Bay using a benthic data-logging respirometer (Fig. 28). The oxygen sensors are linked to benthic domes embedded in the sediment. While the respirometer monitors oxygen concentration in the sediments continuously,

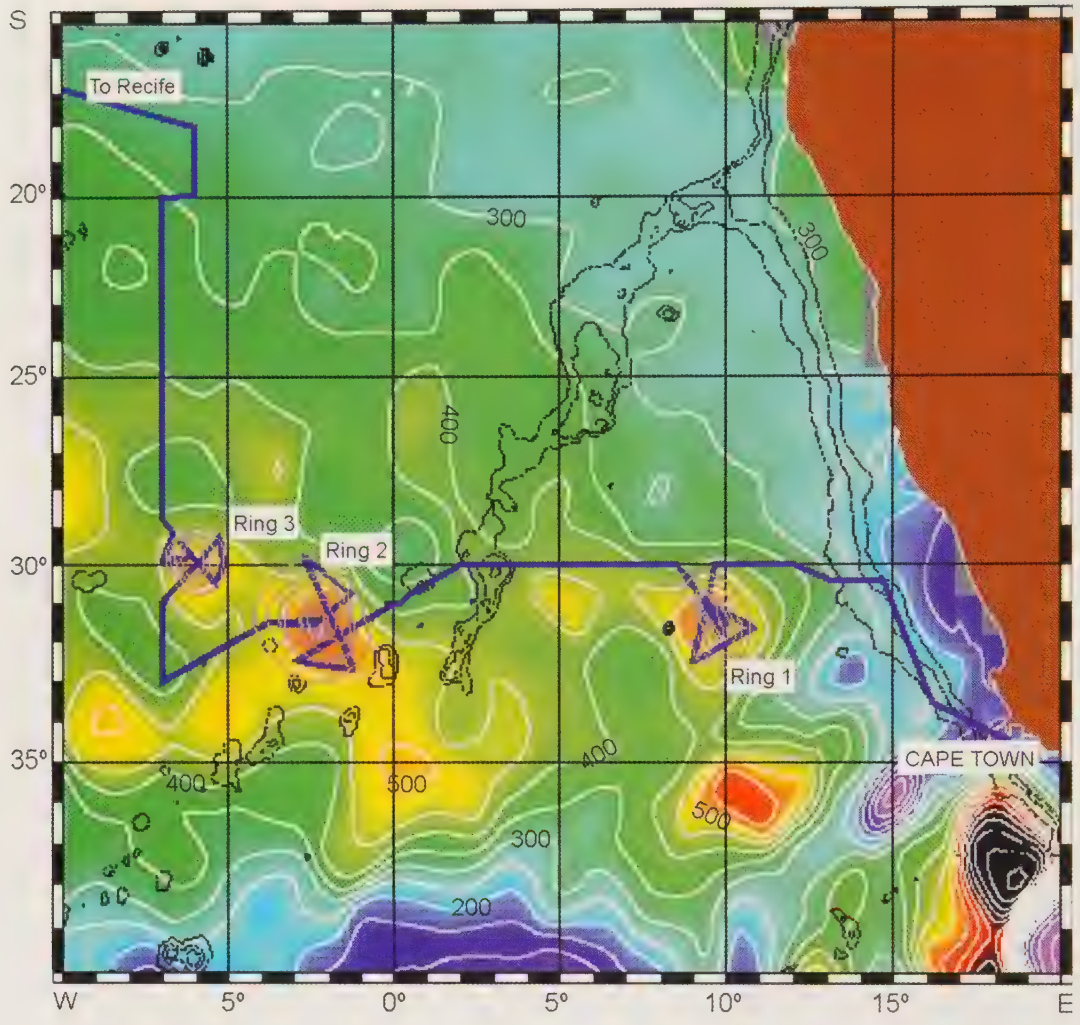

Fig. 29: Thickness (m) of the upper layer in the south Atlantic Ocean, as determined from satellite altimetry and using a simple two-layer model of the ocean, showing the position of three Agulhas rings along the cruise track in September 1997

samples are periodically collected by divers for the analysis of nutrients being released from the sediments. Once the *in situ* respiration experiments are completed, the sediments covered by the domes are sampled for the analysis of marine fauna, bacteria, nutrients and grain size.

Preliminary results obtained so far show that ammonium is released in large quantities under the rafts. Oxygen consumption by the benthic community shows little difference between raft and reference sites. This may be the result of dome design, a problem which has already been addressed for subsequent surveys. The data obtained from the surveys will be integrated into mathematical models that will permit environmental impact assessment at the ecosystem level rather than on a single ecosystem component.

Agulhas rings in the south Atlantic Ocean

Previous hydrographic surveys in the south

Atlantic Ocean have identified Agulhas rings and Brazil eddies in the region of the Cape Basin. Agulhas rings, shed from the Agulhas retroflection south of Cape Town, are known to interact with the upwelling regime of the south-west African coast, affecting the functioning of the upwelling front and shelf-edge processes. Whereas the precise nature and frequency of these effects is still being debated, improved knowledge of the dynamics and characteristics of these eddies is crucial to understanding the biological consequences that such eddy-shelf interactions may have.

In 1997 a series of collaborative projects was initiated in the south-east Atlantic and south-west Indian oceans involving scientists from Germany, the United States, France and South Africa. Collectively, these projects are known as KAPEX (Cape-of-Good-Hope Experiment). KAPEX uses hydrographic surveys and sound-tracked floats to study the exchange and advection of water at intermediate depth (1 000 m) around southern Africa. A local scientist and a local technician participated in the deployment cruise of one of the American components and collected the hydrographic data.

During the cruise aboard the RV *Seward Johnson* in September 1997, three large eddies were encountered in the Cape Basin and east of the mid-Atlantic Ridge (Fig. 29). These eddies, or rings, which had already been detected from satellite altimetry before the cruise, were surveyed using XBT, CTD and LADCP profiling. The ring closest to the Agulhas retroflection, in the Cape Basin, appeared to be a typical Agulhas ring in its first year after shedding. The one farthest away from the retroflection area had a hydrographic structure typical of an Agulhas ring which had experienced two winter mixing periods since leaving the retroflection. The structure of the third ring, near the mid-Atlantic Ridge, was different, indicating that it had been modified by interaction with the subtropical front, either during the shedding process or in its passage across the south Atlantic Ocean.

The results of this hydrographic survey suggest that the interaction of the Agulhas eddies with the fronts and shelf waters near the upwelling region of the Benguela system are more complex than previously thought.

East-flowing currents along the edge of the Agulhas Bank

Two current meters deployed along the 200-m contour of the Agulhas Bank, one 100 km south of Knysna, the other 60 km south of Cape St Francis, revealed a strong current near the bottom moving eastwards. The eastward flow varied with a period of approximately six days, approaching zero or reversing weakly at times. The peak current speed observed in the eastward direction was 54 $cm{\cdot}s^{-1}$ for the Knysna mooring and 74 $cm.s^{-1}$ for that off Cape St Francis. The dominance of the eastward motion can be seen in Figure 30. Oscillatory motion onto and off the Agulhas Bank with the same period of six days was observed with attendant waves of warm and cold water varying from 12 to 6°C. This may well be a hostile barrier confining demersal fish, squid and other species to the bank.

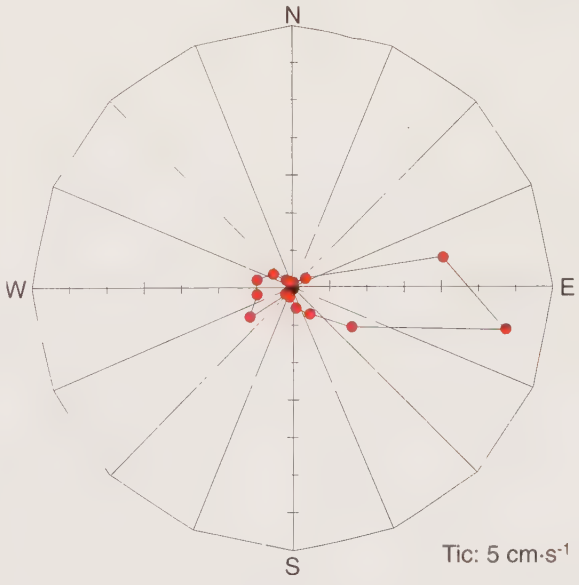

Fig. 30: Average time-weighted currents in each of 16 sectors for the current meter south of Knysna

Nothing is known yet as to the width, depth or eastward extent of this current. It is possible that the feature is an extension of the poleward undercurrent on the West Coast shelf. Recently, an equatorward current, sandwiched between the coast and the swiftly flowing Agulhas Current near Port Alfred, was discovered by British oceanographers on board the R.S. *Discovery*. It may well be that this is a continuation of the current observed on the Agulhas Bank. Further research will be undertaken.

Spawning of anchovy and food limitation on the western Agulhas Bank

As stated earlier, copepods are an important source of food for many fish. Off the Cape coast, the dominant pelagic fish, such as anchovy, sardine and round herring, ingest large quantities of copepods. Food appears to be especially important to these fish when they spawn because spawning ceases when food becomes scarce. This could lead to fewer fish recruiting to the fishery the following year. It is therefore of interest to measure the available food, in terms of copepods, during the spawning season of the pelagic fish, as this provides an index of the scope for successful spawning, a step towards forecasting recruitment.

To evaluate the availability of suitable food throughout the spawning season, a simple mass-balance model of copepod biomass on the western Agulhas Bank, the major spawning ground of pelagic fish in the region, was constructed. Data on copepod abundance and growth, and on fish spawner biomass, were obtained from monthly cruises during two consecutive spawning seasons (September-February of 1993/94 and 1994/95). These data were combined with information from the literature on the daily food requirements of pelagic fish and the proportion of their diet made up by copepods. The model results showed that the availability of food produced on the spawning grounds was in excess of their daily requirements (Fig. 31).

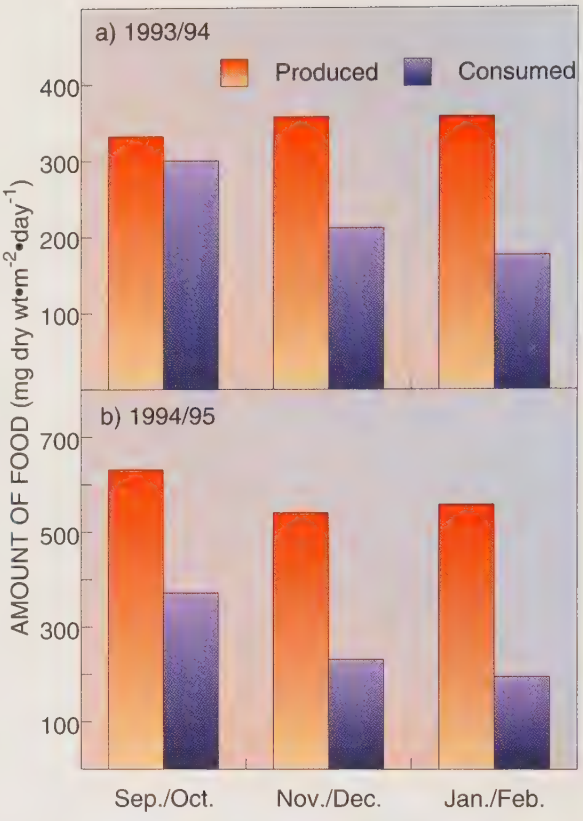

Fig. 31: Within-season variability of daily production by copepods and daily consumption of copepod prey by pelagic fish on the western Agulhas Bank during the spawning seasons of (a) 1993/94 and (b) 1994/95

Previous work has suggested that spawning anchovy are poorly nourished, implying that they may not be obtaining sufficient food. It therefore seems likely that not all the food present on the western Agulhas Bank in the form of copepods may be available to the fish. This could be a consequence of the way that fish feed and the vertical migratory behaviour of copepods. For instance, pelagic fish are visual predators and feed mainly at dawn and dusk, when copepods aggregate near the sea surface to feed. However, copepods migrate less extensively when their food, predominantly phytoplankton, is sparse and located at subsurface depths in the water column, conditions often found on the western Agulhas Bank. As a conse-

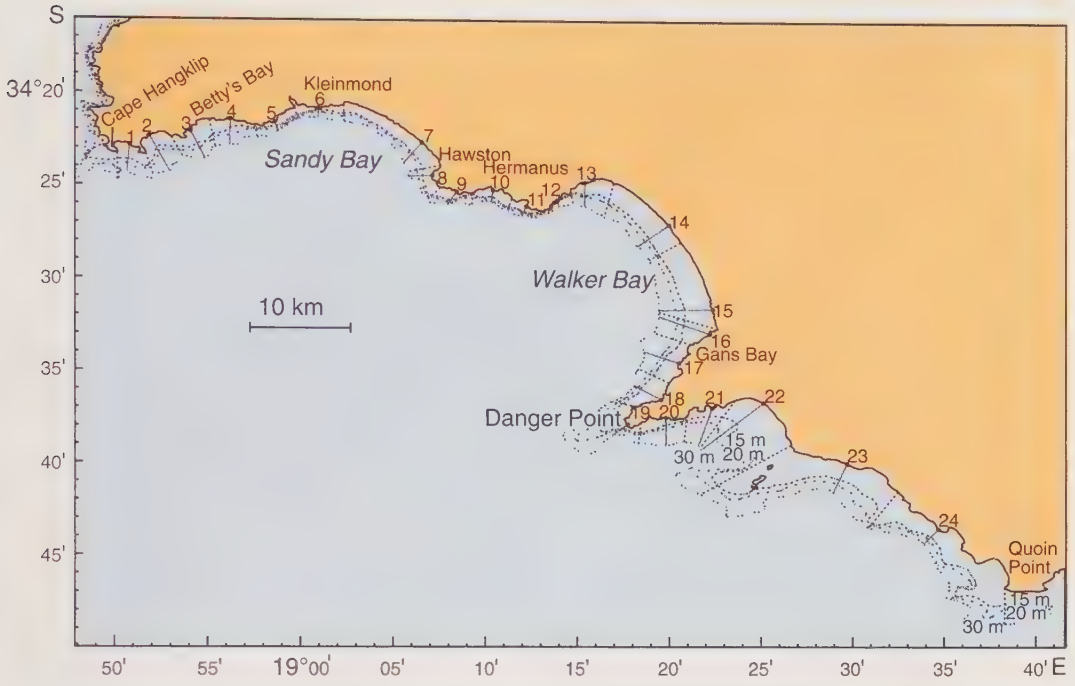

Fig. 32: Diagrammatic representation of the stratified survey design, showing the strata sampled for West Coast rock lobster with hoopnets between Cape Hangklip and Quoin Point

quence, copepods remain deep in the water column, making it more difficult for pelagic fish that use visual cues to locate and capture their prey, so that much of the copepod resource may be unavailable to fish and remains underutilized.

A potential rock lobster fishery east of Cape Hangklip

Although commercially exploitable densities of West Coast rock lobster were traditionally common between Lüderitz and Cape Point, their distribution stretches much farther, from Walvis Bay to East London. However, declining commercial catch rates in the north, coupled with greater productivity in the south, off the Cape Peninsula, and increasing recreational catches east of Cape Hangklip, where commercial exploitation is currently prohibited, have resulted recently in calls to abolish the restrictions on commercial rock lobster fishing on the South Coast. This argument has been strengthened by recent suggestions that the apparent increase in lobster abundance east of Cape Hangklip may be affecting abalone recruitment detrimentally, so jeopardizing the existing fishery for that species, which is already heavily impacted by recreational fishing and poaching (see earlier).

Previous quantitative studies reported that this region harboured relatively sparse lobster populations, limited by the availability of suitable habitat. In contrast, subsequent anecdotal and incidental information suggested a significant influx of lobsters to areas east of Cape Hangklip. During 1996 and 1997, the area between Cape Hangklip and Quoin Point was systematically sampled to provide a scientific understanding of the magnitude and structure of this potential resource. A stratified hoopnet survey design was used (Fig. 32), focusing on the rocky strata within the 30-m isobath, the areas accessible to recreational, subsistence and commercial fishers. Results indeed demonstrate the presence of a substantial lobster resource. However, knowledge

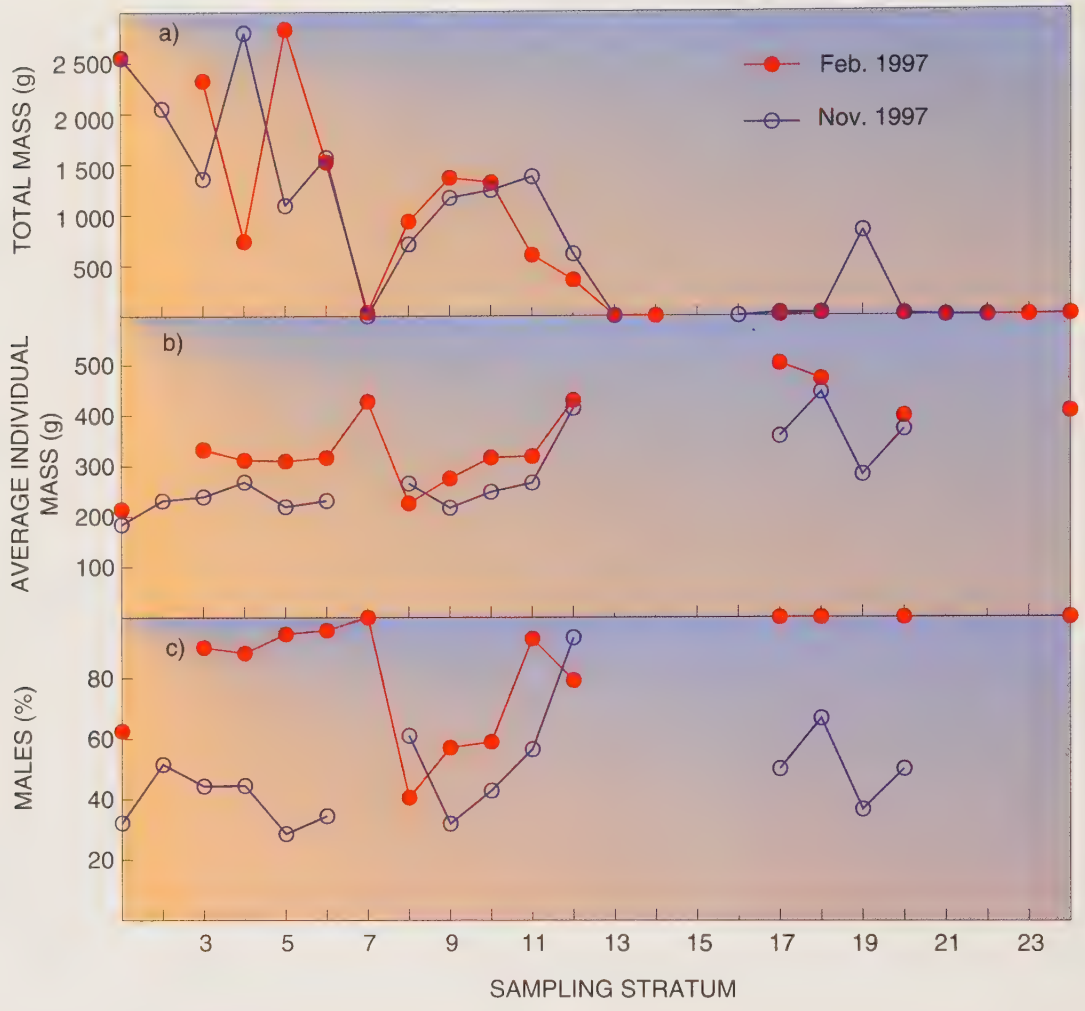

Fig. 33: Spatial variability of West Coast rock lobster resource indicators from hoopnet surveys east of Cape Hangklip in February and November 1997 – (a) total mass, (b) individual mass, (c) relative abundance of males (sampling strata are shown in Fig. 32)

of the magnitude of the resource at a single point in time is insufficient to act as a basis for management; of prime importance is its spatio-temporal dynamics.

Resource indicators obtained from stratified sampling in February and November 1997 generally exhibit similar spatial trends (Fig. 33). Lobster abundance tended to increase from east to west, whereas their average individual size exhibited an increasing trend in a west-east direction. However, there has been a marked temporal change in the demographics of the resource, from a male-dominated population in February to a preponderance of females later in the year. Adult female lobsters grow more slowly than males, and are therefore, on average, smaller. The observed decrease over time in the mean individual lobster mass probably reflects mainly this change in the sex ratio. This can be attributable either to heavy fishing pressure on the larger males, targeted by the recreational fishery, or to sexually differentiated inshore-offshore migration patterns in response to

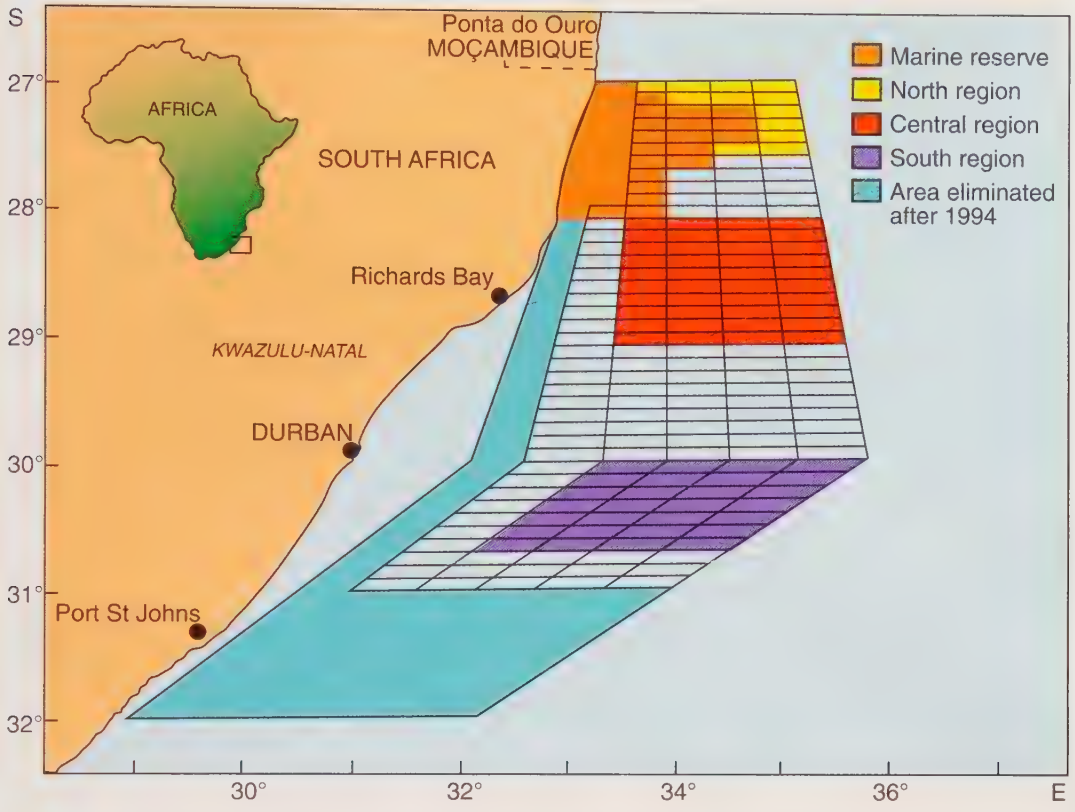

Fig. 34: Sampling area along the KwaZulu-Natal coast, showing the north, central and south regions of the Palinurus delagoae *trap fishery (not to scale)*

moulting and reproductive cycles of the lobsters. Such cyclic behaviour has been noted on fishing grounds farther north, and may have some implications for management of any future fishery.

The origin of the lobster resource east of Cape Hangklip is unclear. However, it is apparent that, not only are these lobsters producing eggs and larvae, but also that the planktonic larvae are recruiting to the benthos. The continued existence of the population may well depend on the dynamics of its food resources and predators. There is already substantial evidence that the presence of many lobsters has resulted in dramatic changes to the macrobenthic community structure. Of particular importance are the suspected interactions between lobsters, sea urchins and abalone. However, these relationships are not static, and the observed increase in the occurrence of octopus in sampling nets toward the end of the survey period may hint at the onset of a natural trend towards decreasing lobster numbers. Although providing some testable hypotheses, these results remain preliminary and require further analysis before they can be used as a basis for managing this resource.

The viability of a trap fishery for Natal deep-water rock lobster

Whereas Natal deep-water rock lobster *Palinurus delagoae* is exploited by trap fishing off Moçambique, it is a target species in a mixed crustacean trawl fishery off KwaZulu-Natal. However, because of the likely presence of a large, virtually unexploited resource in rocky areas inaccessible to trawls, a number of experimental trap fishery

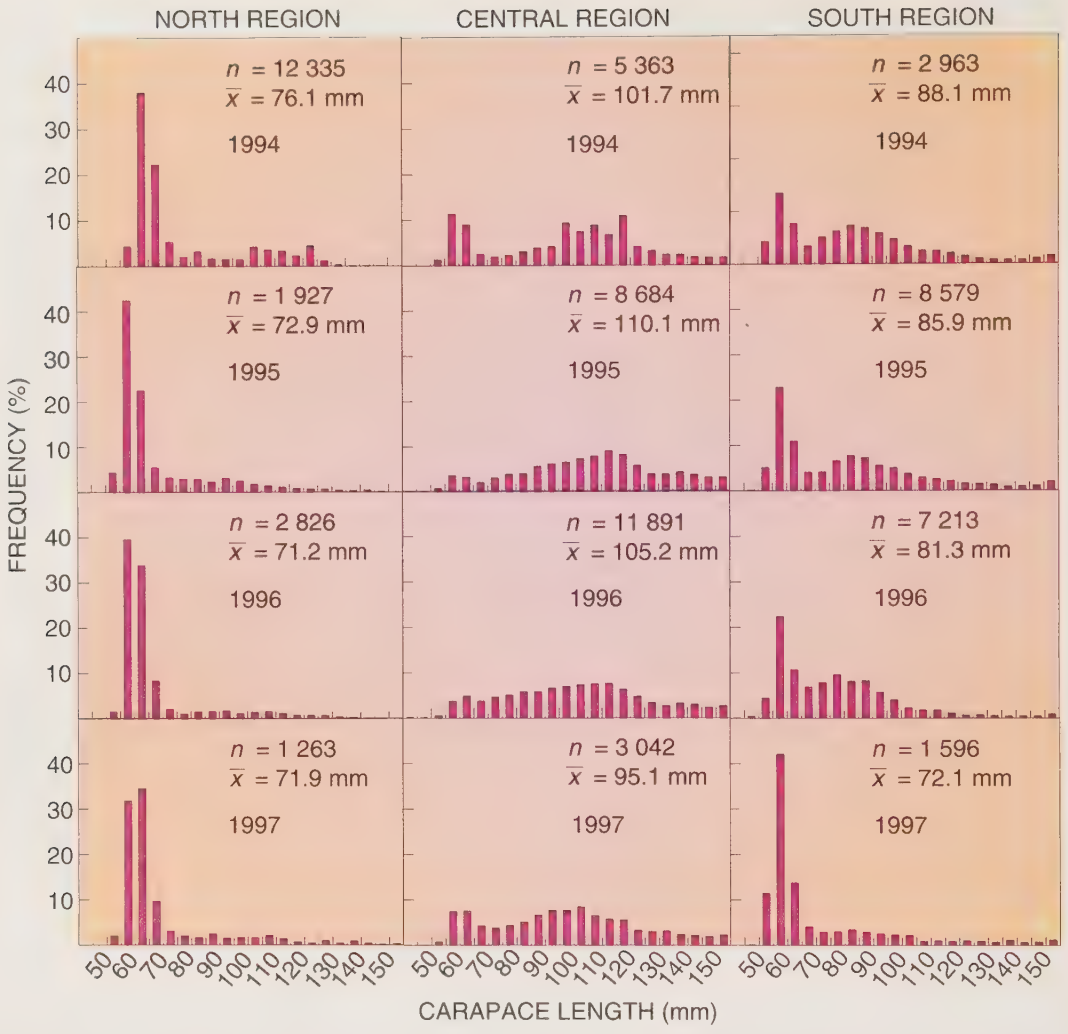

Fig. 35: Size composition of Palinurus delagoae *(sexes combined) caught in traps along the KwaZulu-Natal coast during the 4-year experiment, 1994-1997*

permits was issued in 1994 to test this hypothesis. Commercial longline trap-fishing vessels, accompanied by research monitors supervising gear deployment and recording catch and effort, were utilized for the experiment. It was designed to determine the distribution and abundance of *P. delagoae*, and consisted of an experimental phase (with fixed fishing positions), followed by a commercial phase (without restriction on fishing location) each year. This novel approach provided the incentive for industry participation in the research, besides giving valuable insight into the resource.

Results from this 4-year experiment indicate that the lobsters were distributed in a narrow band 100–400 m deep. Three discrete regions along the coast were identified as prospective fishing grounds (Fig. 34), separated by stretches of sandy-muddy substratum where lobsters were scarce. The mean size of lobsters in the catches increased as fishing depth decreased, suggesting gradual recruitment from deeper water into shallower areas. Size composition of the catches also differed markedly between the three regions (Fig. 35). The central region appears to harbour

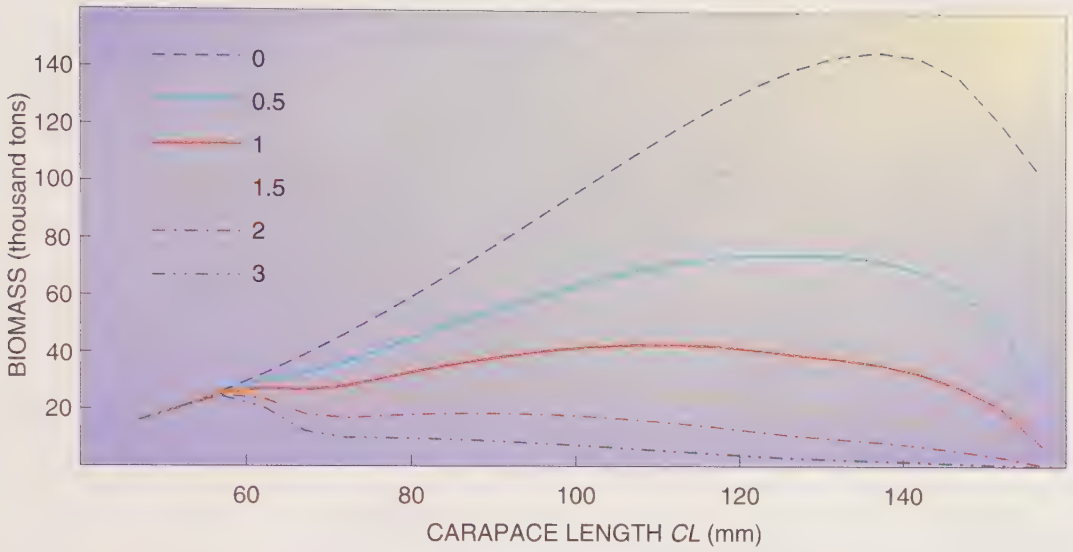

Fig. 36: Projections of biomass of Palinurus delagoae *at increasing levels of fishing mortality, with* F=1 *being the current level*

prime habitat, with a broad size range of lobsters present, whereas the resource appears to taper off towards the south. In the north, predominantly small lobsters were caught because of limited accessibility of fishing vessels to shallow water, where large lobsters are supposedly abundant.

Various criteria were considered to provide an indication of the potential for the resource to be exploited using traps. Catches of *P. delagoae* have declined from 89.5 tons in 1994 to 7.4 tons in 1997, and so did the by-catch of slipper lobster *Scyllarides elisabethae*, from 30 to 2 tons over the same period. A drastic decline in *cpue*, standardized according to year, geographical area, trap-soak time, month of fishing and phase of the experiment was also evident. In all three regions, there were clear declines in the mean size of lobsters. Moreover, recent stock assessments have shown that trap exploitation targets on immature and small mature individuals, so depleting the biomass of medium and large lobsters to a fraction of the population's pristine levels (Fig. 36). Growth is slow, as is generally to be expected in a cold-water species, so recovery of the spawning stock is protracted. Physically, the productive area of *P. delagoae* off KwaZulu-Natal is comparatively limited, and strong currents affect trap efficiency during much of the year. Taking all these aspects into account, it is clear that a commercial trap fishery targeted at *P. delagoae* alone has limited potential. For the time being, therefore, it has been halted.

The effect of winter winds on Agulhas sole catches

Catch rates of Agulhas sole vary according to sediment type and depth of the water column, as well as seasonally. Analysis of catch rate data in the coastal zone on the South Coast over the past few years revealed that catch rates peaked in winter (April–July), between Cape Agulhas and Cape Infanta (Fig. 37). There is, however, also considerable interannual variability in this trend, which appears to be related to fluctuations in the wind pattern at that time. The Cape Agulhas Pressure Index (CAPI), which is a measure of the pressure difference between Cape Agulhas (35°S) and the storm belt at 40°S, was used as an indicator of wind strength and direction. In winter this index is negative, suggesting that north-westerly winds are preva-

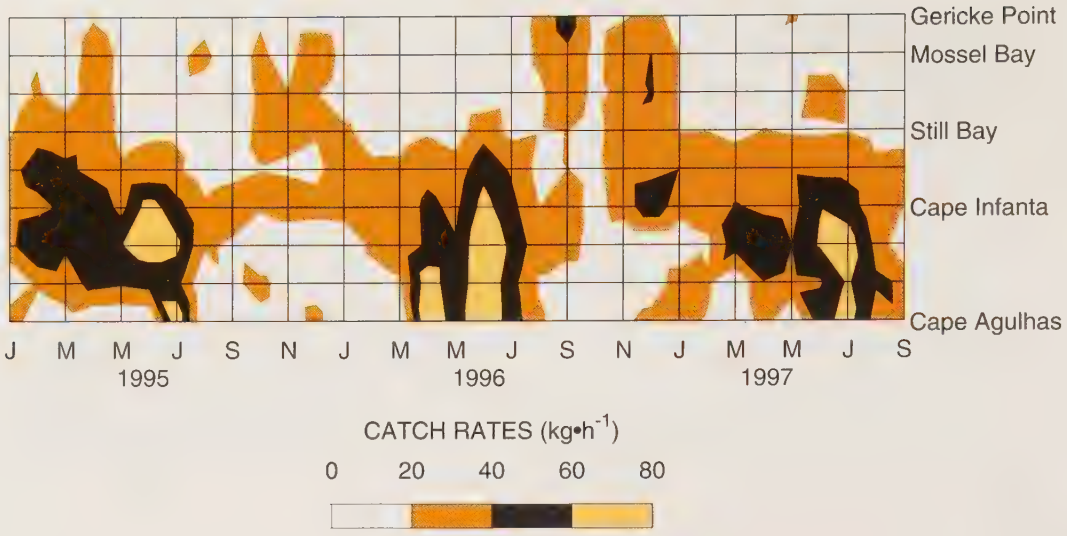

Fig. 37: Contour map of the spatio-temporal distribution of catch rates of Agulhas sole in the coastal zone between Cape Agulhas and Gericke Point

lent. During the period 1982–1997, highest catch rates were usually observed during years when north-westerly winds in winter were strongest, whereas lower catch rates coincided with years of less characteristic winter conditions of wind (Fig. 38). Indeed, there is a significant correlation between mean catch rates of sole during April–July of each year and the minimum value of the CAPI over the same winter period, with 62% of the variability in the catches being explained by changes in wind strength. Whether this relationship is causal remains unclear and requires further investigation.

Winds affecting the vertical distribution of deep-water hake

The Institute's hake assessment programme uses commercial catches and bottom trawl survey estimates to determine resource fluctuations and catch limits. This approach assumes that there is a linear relationship between abundance levels and catch rates, i.e. that the proportion of fish available to the trawling gear is constant relative to the total population. Deviations from this ratio are expected to be random, therefore not affecting trends in the time-series. In

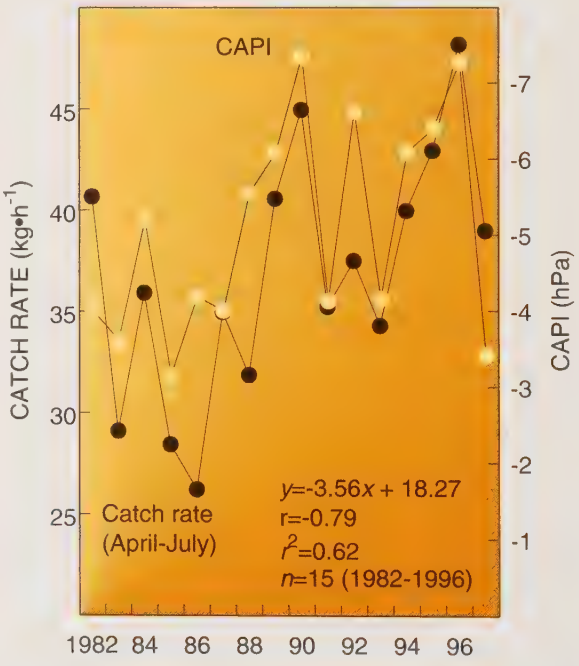

Fig. 38: Annual trends in the average winter catch rates of Agulhas sole and the minimum (most negative) deviation in winter of the Cape Agulhas Pressure Index (CAPI), 1982–1997

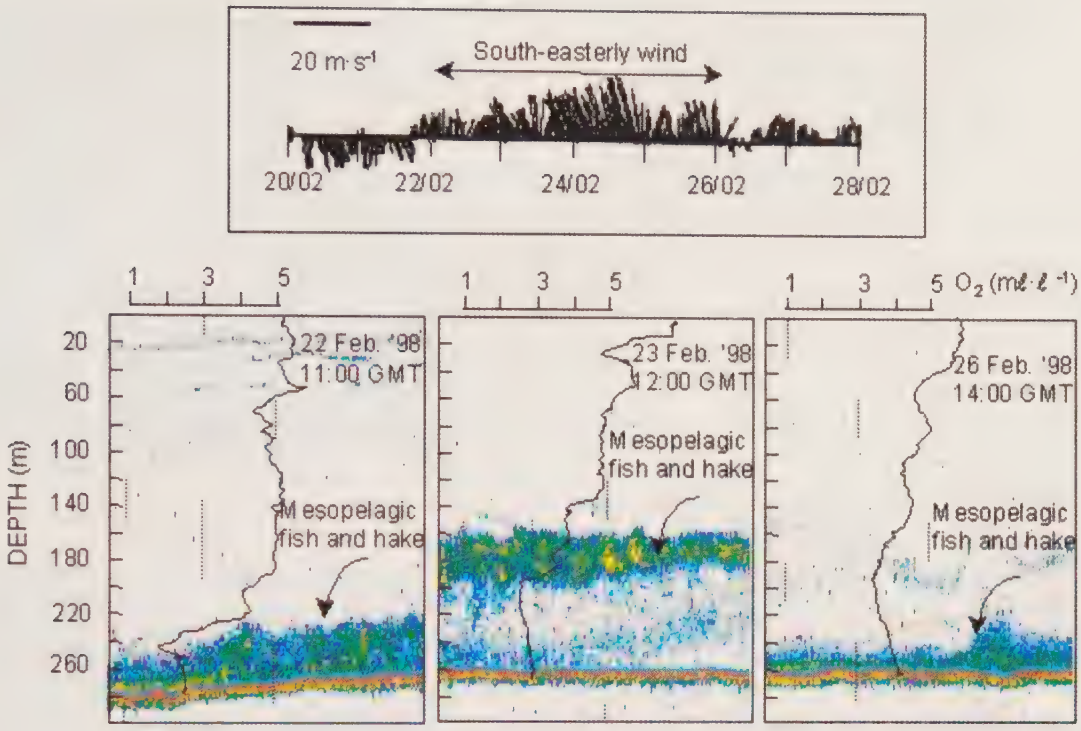

Fig. 39: Echo-charts showing the vertical distribution of fish targets at the onset, peak and relaxation of a period of strong south-easterly winds, with profiles of oxygen concentration superimposed

recent years, commercial fishers reported strong south-easterly winds impacting negatively on the catchability of hake by bottom trawls, particularly on the deep trawling grounds off the Cape Peninsula. This phenomenon, which was usually associated with the presence of green, murky water near the surface, was studied recently.

Data were collected day and night at a fixed station off Slangkop, in water 270 m deep, immediately before, during and after a bout of strong south-easterly winds using multifrequency acoustics combined with a range of different trawling gear (Fig. 39). Prior to and after the wind event, a scattering layer constituting mainly mesopelagic fish and deep-water Cape hake *Merluccius paradoxus*, was found close to the bottom during the day. This distribution pattern is to be expected for demersal fish communities during daylight. Conversely, when the south-easterly wind was strongest, this scattering layer had shifted from near the sea bed into midwater. Concomitantly, the level of low-oxygen bottom water had risen over a similar depth range of about 90 m, indicating a strengthening of the low-oxygen poleward undercurrent, which transports water from near the sea bed onto the outer continental shelf. The murky appearance of the surface waters is likely to result from offshore Ekman transport of nearshore phytoplankton-rich waters during this wind-driven upwelling process.

Preliminary analysis of historical current-meter data from the study area suggests that, during periods of intense south-easterly winds, near-bottom water is transported in a south-easterly direction at a rate of 2.5 km·day^{-1}. However, north-westerly flow was recorded 150 m off the bottom during the cruise. By regulating their vertical position relative to the water column

current field, hake and mesopelagic fish species are thought to control their horizontal displacement and so ensure maintenance within their preferred habitat. Other possible hypotheses, such as behavioural responses to low-oxygen conditions or trophic interactions between hake and their prey, will be explored in future.

Studies on the reproduction of Cape hakes

The experimental hake-directed longline fishery has shown that longliners catch a much higher proportion of adult females than do trawlers. Such selectivity may exert severe pressure on the spawning stock of Cape hakes, and has opened a debate as to future allocations of catches to each fishing sector. An understanding of the potential impact of increased female mortality on the spawner population is therefore critical to stock assessment. However, little research has specifically addressed the spawning pattern and fecundity of Cape hakes, knowledge essential for the validation of certain assumptions underlying stock assessment models.

A recent histological study of the ovaries of Cape hakes, conducted under the auspices of the longline programme, has verified their serial spawning pattern and has also yielded the first-ever estimates of batch fecundity. To investigate the spawning pattern, ovaries of females in various length-classes were categorized into maturity stage. That hakes do not broadcast all their eggs in a single spawning event, but in several batches, is evidenced by the presence of oocytes in different stages of development in all ovarian classes examined. Also, the presence in partially spent ovaries of post-ovulatory follicles, indicative of previous spawning, in conjunction with yolked oocytes, suggesting consequent spawning, confirms that *M. capensis* and *M. paradoxus* are fish that spawn serially.

Batch fecundity, i.e. the number of eggs released in a single spawning event, was determined according to the Hydrated Oocyte Method.

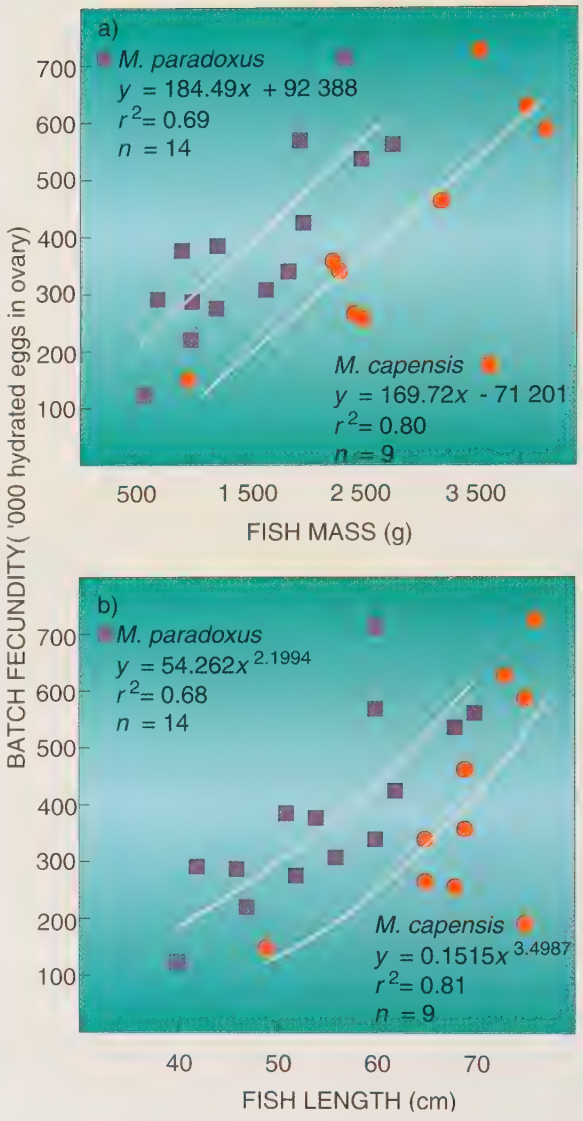

Fig. 40: Relationship between batch fecundity and (a) fish mass and (b) fish length for Merluccius capensis *and* M. paradoxus

Mean batch fecundity was found to be 417 202 eggs·female^{-1} for *Merluccius capensis* and 384 713 eggs·female^{-1} for *M. paradoxus*. Batch fecundity increased with mass and length of females (Fig. 40), confirming one of the assumptions of conventional yield-per-recruit models. Once information has been gathered on spawning frequency and the duration of the spawning season, these results will make it possible for the

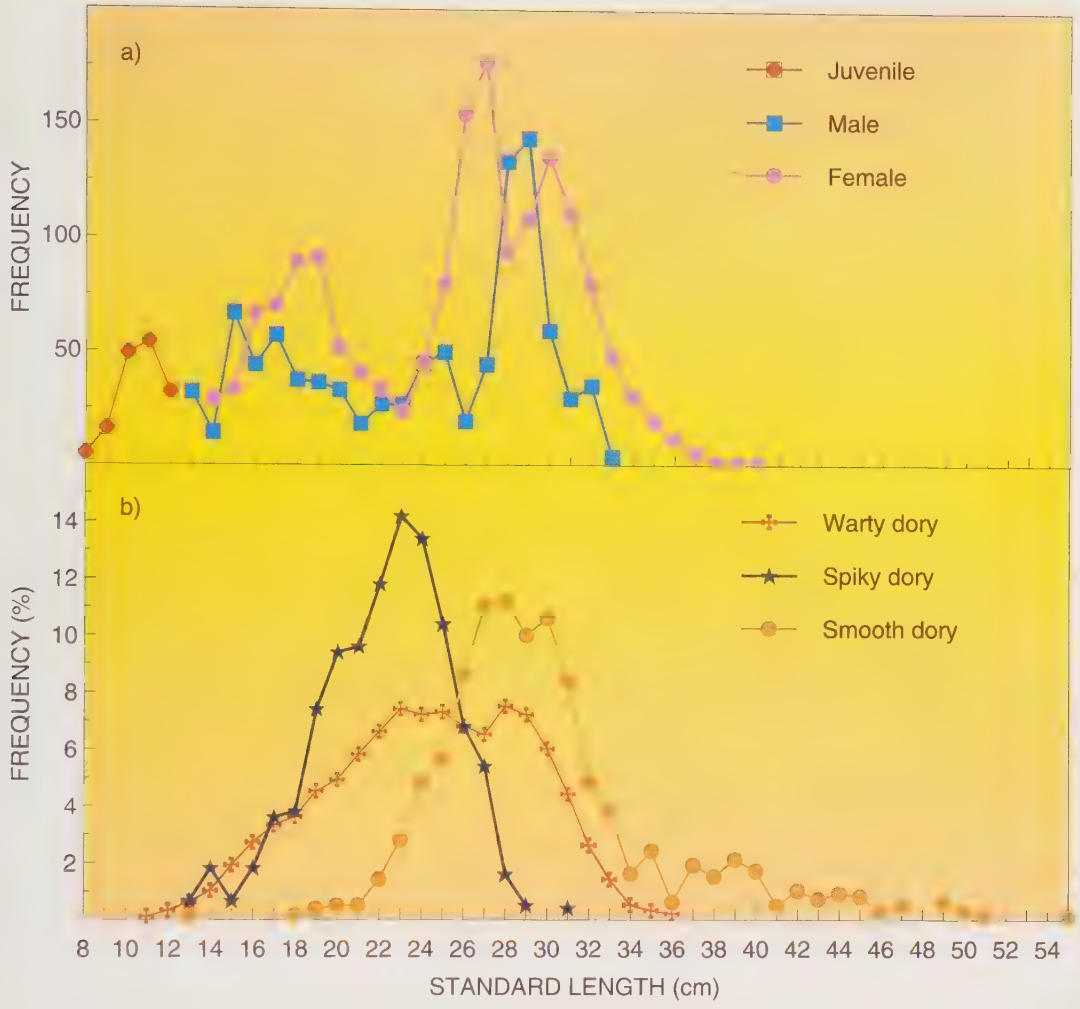

Fig. 41: Length distributions of (a) orange roughy and (b) three oreo-dory species from catches made off South Africa

Daily Egg Production Method to be used in future stock assessments of Cape hakes.

On the biology of some deep-sea fish

Until recently, little was known about the biology and life history parameters of the orange roughy and its associated by-catch species with commercial potential. These include the oreo-dories *Allocyttus verrucosus* (warty dory), *Neocyttus rhomboidalis* (spiky dory) and *Pseudocyttus maculatus* (smooth dory). These fish are usually found at depths of 500–1 000 m, but warty dory also inhabit deeper water up to 1 500 m. All these deep-sea species are distributed from Walvis Bay to the Cape, but the range of orange roughy extends to Durban and that of warty dory to Maputo, Moçambique.

Aggregations of orange roughy appear to be thinly distributed over extended areas along the West Coast. The fish are caught in small quantities of up to a few hundred individuals and, the larger the aggregation, the bigger the fish. Off the west coast of South Africa the nature of the

sea floor may be less suitable for the species than off Namibia. The sea bed south of the Orange River is mostly soft and muddy, with few interruptions in its profile. Where the bottom topography is broken and rough, there are usually holes with steep, hard sides, surrounded by flat muddy patches, but no elevated pinnacles and seamounts, the habitat preferred by orange roughy.

In catches off South Africa orange roughy range in length from 9 to 40 cm (Fig. 41a), but they can attain 69 cm. Their length distribution is bimodal, with peaks at 16–18 cm and 26–30 cm. Females attain a larger maximum size than males. Length-at-50%-maturity is about 22–24 cm whereas 100%-maturity is reached only at 34 cm. In most length-classes females outnumber males, perhaps indicating that non-spawning aggregations have been fished. The gregarious orange roughy are group-synchronous spawners, producing a single batch of eggs. Spawning takes place during a brief (one month) winter season, when they form dense aggregations. Characterized by slow growth and late maturity, orange roughy are particularly vulnerable to overexploitation.

Oreo-dories have typically unimodal length distributions, with modes at 23–29 cm for warty dory, 23–24 cm for spiky dory, and 27–30 cm for smooth dory (Fig. 41b). The three species reach 50%-maturity at about 24, 28 and 32 cm respectively. Unlike orange roughy, size-based sex ratios of the oreo-dories appear to be randomly distributed. Length-mass relationships were established for orange roughy and the three oreo-dory species and, at similar lengths, orange roughy weighs the most and smooth dory the least (Fig. 42).

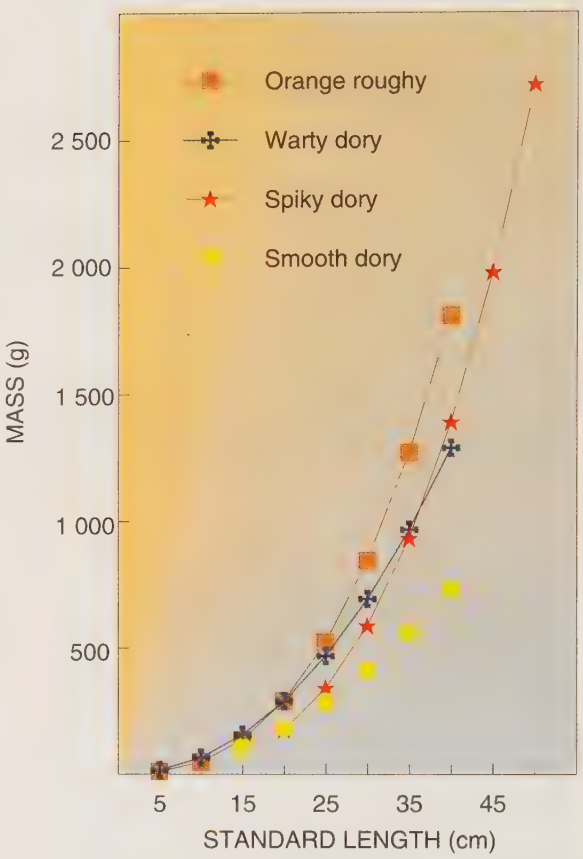

Fig. 42: Length-mass relationships for orange roughy and three oreo-dory species

A new breeding seabird for South Africa

During joint surveys undertaken by the Institute and the Avian Demography Unit of the University of Cape Town, a new species of seabird, Leach's storm petrel *Oceanodroma leucorhoa*, has been discovered breeding in South Africa. This brings the number of seabirds breeding in the country to 15 species.

Breeding by Leach's storm petrel at Dyer Island was suspected in November 1995, when at least 17 birds were sighted on the island. Some were occupying suitable nest sites in dry stone walls, and there was a high degree of vocal activity at night. In November 1996, there was a minimum of 19 birds at the island. At least one of these was incubating an egg. In February 1997, investigation of the chamber in which the egg had been found revealed the presence of a large chick. This chamber was empty in March 1997, and it is assumed that the chick successfully fledged. In February 1998, six chicks were found at Dyer Island, two of which were banded. One adult was also caught and banded (Fig. 43).

Fig. 43: The Leach's storm petrel Oceanodroma leucorhoa *adult that was banded at Dyer Island (B. M. Dyer, SFRI)*

In October and December 1997, the possibility of Leach's storm petrel breeding at other islands off South Africa's west coast was investigated. At least one bird was heard calling from within a dry stone wall at Dassen Island. It is likely that it was breeding, but this could not be ascertained without excessive disturbance. One adult was caught and banded. In the summer of 1997/98, three dead adults were found at Dassen Island, probably killed by cats. There was no indication of the presence of Leach's storm petrel at other islands off the West Coast, although the possibility of the species breeding at some of these islands cannot yet be excluded. However, what is clear is that the South African population is very small, probably of the order of 10–25 pairs.

Breeding by Leach's storm petrel in South Africa is the first confirmed record of breeding by the species in the southern hemisphere. Leach's storm petrel had previously been considered a non-breeding visitor to oceanic waters of the southern Atlantic and tropical Pacific oceans from its breeding grounds in the northern hemisphere. Because of the isolation of the South African breeding population and its small size, it will be necessary to implement steps to secure the species' survival here. The most pressing of these are maintenance of suitable breeding habitat and control of predators, especially cats at Dassen Island.

Bank cormorant a decreasing species

The bank cormorant *Phalacrocorax neglectus* is one of seven species of seabird that are endemic to southern Africa. It breeds only in the Benguela ecosystem, from Hollams Bird Island in Namibia to Quoin Rock in South Africa. During the period 1978–1980 there were an estimated 8 672 breeding pairs. By 1995–1997 this number had fallen to 4 888. During these periods the South African population was respectively 1 506 and

1 113 pairs. In 1997, the conservation status of the bank cormorant was reassessed.

In terms of IUCN (World Conservation Union) criteria, a species that has decreased in abundance by 20–50% in the three most recent generations is classified as "vulnerable", which means that it "is facing a high risk of extinction in the wild in the medium-term future". Generation is measured as the average age of parents in the population, and may be estimated by adding the average life expectancy of breeders to the mean age at first breeding. The generation time of bank cormorants is thought to be about 7.5 years. Hence, the interval between the mid-points of the two periods considered, 1979 and 1996, 17 years, is equivalent to 2.3 generations.

Natural fluctuations, as observed at Ichaboe Island in Namibia as a consequence of changes in the foodweb, are not considered part of a population decrease. After these have been accounted for, the population in South Africa, Namibia and overall has decreased by 26–34% in the three most recent generations. Therefore, throughout its range, the bank cormorant merits classification as "vulnerable".

The factors mainly responsible for the reduction in the bank cormorant population have been human disturbance, which has led to the loss of four colonies (three in South Africa) and reduced populations at six others (two in South Africa), and displacement of birds from breeding sites by Cape fur seals *Arctocephalus pusillus pusillus*.

Populations of bank cormorants at three of South Africa's larger islands have fallen alarmingly in the 1990s (Fig. 44). At Lambert's Bay, there were 33 breeding pairs in 1989 but only one in 1997. The colony has been influenced by encroachment of seals onto the island. At Malgas Island, there were 194 pairs in 1990, but just 32 in 1997. At Dassen Island, the population fell from 204 pairs in 1989 to 25 in 1997. These latter decreases may have resulted from decreased food resources, mainly rock lobster, around Malgas and Dassen islands.

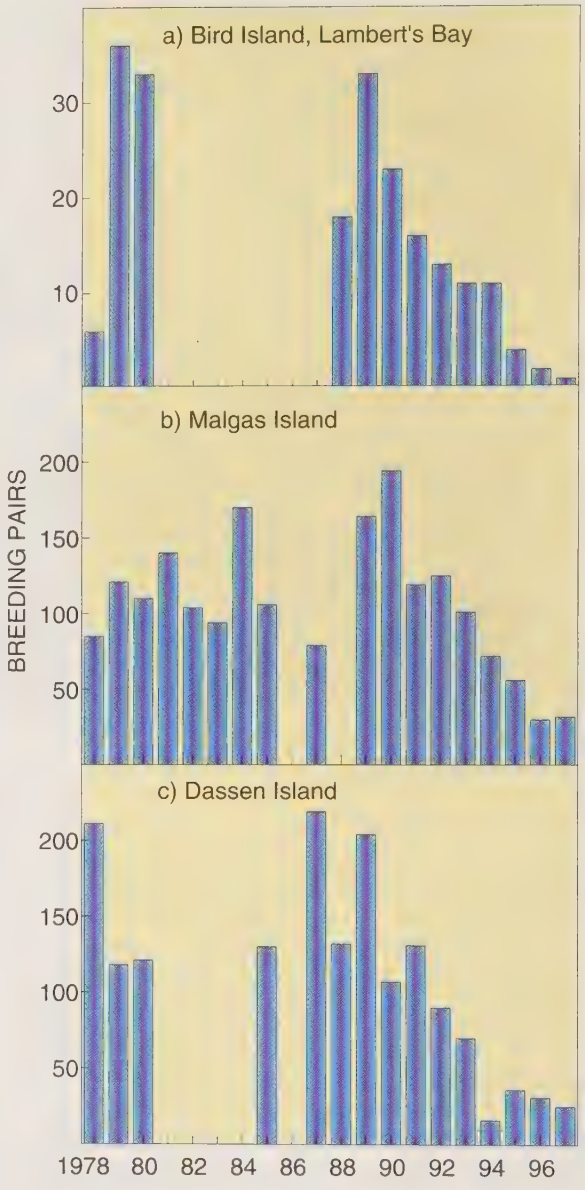

Fig. 44: Trends in breeding populations of bank cormorants, decreasing over the period 1989–1997, at (a) Lambert's Bay, (b) Malgas Island, (c) Dassen Island

Improving the conservation status of bank cormorants will depend on securing existing breeding sites against disturbance by humans and displacement by fur seals, and possibly also ensuring adequate food resources around major colonies.

Fig. 45: Rockhopper penguins Eudyptes chrysocome filholi *at Marion Island (B. M. Dyer, SFRI)*

Research in the Southern Ocean

Research in the Southern Ocean is undertaken by the Institute in support of South Africa's commitment to the 23-nation Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). The research is divided into three major components, which provide vital input into the CCAMLR Ecosystem Monitoring Programme (CEMP). The first research component focuses on the resource potential and management of Antarctic krill *Euphausia superba*. In cooperation with scientists at the University of Cape Town, Sea Fisheries staff remain at the forefront of developing models of the spatial distribution of krill as a basis toward management of the krill fishery and for the study of krill predator-prey relationships.

Acoustic information, collected during research cruises to the Southern Ocean, is used to describe physical and biological characteristics of krill aggregations and their patchiness. Factors which induce the formation, maintenance and dispersal of aggregations are identified through correlation of aggregation parameters with prevailing biotic conditions.

A key factor in evaluating the resource potential of krill is the development of estimators of aggregation parameters which will improve current assessment procedures of krill abundance. The use of geostatistics and GLM techniques has been considered as a new facet of this process. Strategies to estimate krill distribution and abundance at various levels of precision and spatial scales have also been developed and are crucial for a number of CCAMLR initiatives.

The monitoring of seabirds at Marion Island constitutes the second Southern Ocean research component. From 1994 to 1997, the Institute undertook surveys on the island to estimate the breeding populations of three species of penguin: gentoo penguin *Pygoscelis papua*, rockhopper penguin *Eudyptes chrysocome* (Fig. 45)

Fig. 46: A large Patagonian toothfish Dissostichus eleginoides *being heaved onboard a commercial vessel (M. Purves, SFRI)*

and macaroni penguin *E. chrysolophus*. The world population of gentoo penguins constitutes some 260 000 breeding pairs, of which the 1997 population at Marion Island contributes only 0.4%. Counts of the number of breeding pairs on the island over the 4-year period declined from 1 352 in 1994 to 956 in 1997, whereas the estimate for 1984 was 888 pairs. Therefore, although decreasing recently, the population at Marion Island has been stable in the long term.

The population of rockhopper penguins at Marion Island was 173 000 pairs in the 1994/95 breeding season and 150 000 pairs in 1996/97. The error on the 1996/97 count was estimated to be 22 000 pairs (15%). Previous estimates fluctuated between 93 000 and 212 000 pairs during the 1970s and 1980s. The rockhopper penguin at Marion Island is the eastern race *E. c. filholi*. The world population of this race is estimated to be 832 000 pairs, of which the 1996/97 population at Marion Island amounts to 18%.

The number of breeding pairs of macaroni penguins is estimated, on a global scale, at about 9 000 000, of which the Marion Island population in 1996/97 contributed 4%. Counts of 398 000–434 000 pairs on the island during the period 1994–1997 compare well with estimates of 450 000 pairs in 1976 and 405 000 pairs in 1983, indicating long-term stability.

The third area of Southern Ocean research revolves around the management of the longline fishery on Patagonian toothfish *Dissostichus eleginoides* (Fig. 46) which has developed in the vicinity of the Prince Edward Islands over the past two years. Data collected from an integrated monitoring scheme, using scientific observers and satellite-tracking, deployed by South Africa last year, have been used by

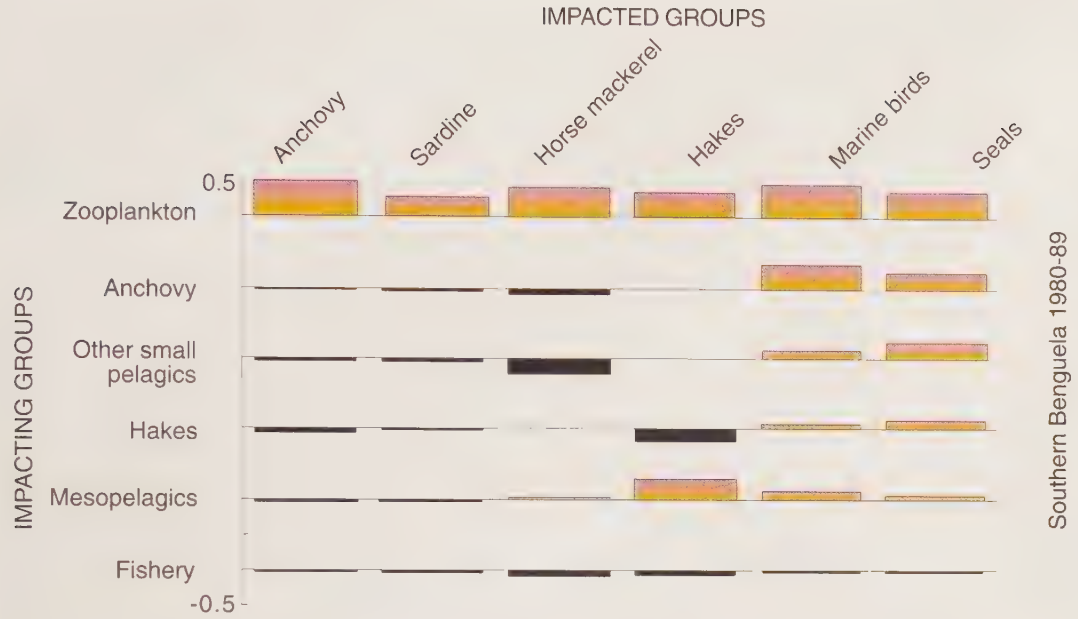

Fig. 47: Mixed trophic impacts of some important ecosystem components in the southern Benguela, 1980–1989

CCAMLR in the setting of catch limits for the region as a whole. However, indications are that as much as 20% of the pre-exploitation spawner biomass may have been removed from the islands' EEZ during the first year of fishing. Coupled with a marked decline in catch rates and a downward trend in the mean size of fish caught, the future potential of this fishery appears to be bleak. Consequently, local scientists have entered into negotiations with their counterparts at the Marine Renewable Resources Assessment Group at the University of London with a view to undertaking a fisheries-independent monitoring survey of Patagonian toothfish stocks around the Prince Edward Islands in the near future.

Ecosystem modelling and fisheries management

Until fairly recently, ecosystem considerations have been largely excluded from any formal fisheries management advice. Management has been based on single-species approaches, with some multispecies modelling being attempted. However, there has recently been a shift in perspective towards managing fisheries at the ecosystem level, and modelling tools have been developed to examine the structure and functioning of ecosystems.

One such ecosystem modelling tool is the widely-used ECOPATH model, which has been under development since 1987 by the International Centre for Living Aquatic Resources Management (ICLARM). ECOPATH is based on the simple balance equation: Consumption = Production + Respiration + Excretion. It enables the construction of a trophic flow budget, creating a balance for each component, or "box", in the model and for the flows between compartments. Unknown parameters are estimated where possible. For each group of organisms within a system in steady state, input balances output over a given period of time. A set of simultaneous linear equations describes the interactions between groups within the ecosystem.

The trophic functioning of the southern Benguela

system during the 1980s, when anchovy were the dominant pelagic fish, was modelled using ECOPATH. In order for the model to balance, input and output parameters of certain groups had to be re-evaluated and adjusted, taking their dietary requirements, as well as predation and cannibalism, into account. Mixed trophic impact assessment was used to evaluate the relative impact that a change in the biomass of one component would have on other components of the ecosystem (Fig. 47). Zooplankton favoured all the main groups in the southern Benguela. The potential positive effects of anchovy (prey) on hake (predator) were counteracted by competition between hake and anchovy for zooplankton. Similarly, horse mackerel and other small pelagics competed for zooplankton prey, resulting in small pelagics having a negative impact on horse mackerel.

The southern Benguela ecosystem model further showed that mesopelagic fish (lanternfish *Lampanyctodes hectoris* and lightfish *Maurolicus muelleri*) are an integral part of the foodweb, forming an important food source for top predators such as hake. Despite small catches, the fraction of the total production of mesopelagics required to support their predators is high, indicating that they are not underexploited. The model indicates also that marine mammals consume relatively more food off South Africa than in other systems. Moreover, whereas the importance of top predators in the southern Benguela is highlighted, the need for improvement on parameter estimates of demersal fish and chondrichthyan predators was emphasized.

Given the gradual recovery during the 1990s of sardine, possibly replacing anchovy, construction of an ECOPATH model of the southern Benguela for this decade is already underway, and modelling of the 1950s and 1970s, when sardine stocks were at high levels, is also planned. Such a comparative approach will not only facilitate refinement of the 1980s model, but will also provide insight into the manner in which ecosystems function under different scenarios of species dominance. Moreover, even during periods when the same species is dominant, the ecosystem may function differently. Similar modelling work has already been done for the northern Benguela off Namibia. It is expected that, through such modelling, differences in harvest and conservation strategies between the two ecosystems will be identified. This should ultimately lead towards improvement of fisheries management in the two regions.

Research and development

During the past year, the engineers and technicians of the Institute's Research Engineering Services unit were committed mainly to the general maintenance of the scientific systems aboard the research vessels, as well as the preparation of research cruises. However, a number of new projects were also started.

The CTD Multi-Array, with sensors for the routine measurement of salinity, temperature, depth, fluorescence, turbidity, oxygen and light in the water column, described in previous issues of *Research Highlights*, was triplicated. The acquisition and handling of data on the research fleet now runs on three identical systems. The performance of the new CTD Multi-Arrays on board F.R.S. *Africana*, F.R.S. *Algoa* and R.V. *SA Agulhas* has so far been very encouraging.

A multi-function communication circuit board was designed, manufactured and tested. It will serve as an interface between the ship's GPS receiver and alien scientific equipment usually brought on board by visiting scientists. This new board can convert the format of the GPS data string into any format that a new instrument requires, enabling the two devices to communicate with each other. This circuit board will also be particularly useful when the Data Distribution Systems (DDS) on the ships are upgraded from a DOS-based computer system to run in a MS Windows environment. A market investigation of currently available hard- and software options has already been conducted, indicating that the software can be written in-house using MS Office 97.

Development work was done on the Multi-Logger, a miniature, battery-powered Temperature-Depth-Flow-measuring instrument. It is designed to be deployed on miniature Bongo nets towed from small boats without the need for a slipring winch. The original specifications, to monitor depth, temperature and water flow through the net, have been expanded on to allow virtually any environmental sensor to be plugged into the instrument.

To keep abreast of the rapidly advancing electronics industry, the Institute also devoted time to study the new Atmel single-chip microprocessor. This is a very small chip substituting four of the chips normally used in-house for design projects. It will allow drastic miniaturization of instruments to be manufactured in-house in the future.

A new national marine research aquarium

On 24 April 1998, the Institute's new Research Aquarium in Sea Point (Fig. 48a) was officially opened by the Hon. Minister of Environmental Affairs and Tourism, Dr Z. Pallo Jordan (Fig. 48b). This followed a long process of careful planning and design by a project team of in-house specialists and private sector architects. The plans included the construction of a new seawater intake pipeline, the demolition of the original 1939 building, once Cape Town's public aquarium, and its replacement by a state-of-the-art research aquarium, and the refurbishment of the peripheral buildings to conform with modern design. Demolition works started in the middle of 1996 and construction of the new research facility was eventually completed at the end of 1997.

The research aquarium is the first multi-functional research facility of its type in Africa and one of the most modern and technologically complex in the world. Spread over three levels, the building houses a public information centre with static displays of ongoing research at the

Fig. 48: Sea Fisheries' new national marine research aquarium – (a) the R16m building on the beach front in Sea Point. (b) Dr M. Mayekiso (Chief Director: Sea Fisheries) and Dr A. I. L. Payne (Director: SFRI) with Ms E. ka Nkosi-Shandu (Deputy Minister: Public Works) and Dr Z. P. Jordan (Minister: Environmental Affairs and Tourism) at the opening ceremony, (c) the facility for the mass culture of phyto- and zooplankton, (d) the 10-m high mesocosm (C. Ward/H. M. Verheye, SFRI)

Institute and an auditorium seating 100 people, in addition to various general purpose-built wet and dry laboratories, six constant-temperature laboratories, and a radio-isotope laboratory. The facility also provides a variety of well-serviced open-plan research areas with differing natural light conditions and the availability of 0.2, 1, 10 and 18-μm filtered seawater. A total floor area of 1 600 m^2 is available for running-seawater experiments under natural light. A total of 10 × 1 200-ℓ tanks for the mass production of algae can, via a computer-controlled, automated dispenser system, feed another 10 × 7 000-ℓ tanks in which mass cultures of zooplankton can be maintained (Fig. 48c). Adjoining an observation room are three interconnected fibreglass tanks (diameter 3 m) equipped with an overhead video rail system.

Besides a 5.5-m high observation tank (diameter 4.5 m) for behavioural studies on pelagic fish and cephalopods, the research aquarium also boasts a 10-m high, stainless steel column (diameter 1.5 m) with observation and sampling ports at different depths (Fig. 48d). This mesocosm facility allows vertical gradients of various water column properties to be simulated to study, *inter alia*, their effects on the vertical distribution of phytoplankton and the migratory behaviour of zoo- and ichthyoplankton. There is also a penguin pool, allowing research on the feeding behaviour of those seabirds.

Another feature of the research aquarium facility is that the interior environment, the temperature regimes in the constant-temperature laboratories, and the status of the pumps, compressors and sensors linked to any experiments, are all being monitored continuously by a computerised environmental control and monitoring system. A stand-by generator supplies power to all essential services in the event of a power failure.

The design of this new research aquarium is aimed at maximum versatility, enabling marine scientists to study many aspects of a wide variety of marine organisms under a broad spectrum of simulated environmental conditions. It will also assist researchers in identifying commercial opportunities in aquaculture and in assessing the suitability of indigenous organisms as potential culture species in the development of an environmentally responsible aquaculture industry. Operated as a national facility, the research aquarium provides opportunities for research on living marine resources and for the promotion and development of mariculture. It is expected to make a significant contribution to South African marine science in general.

THE INSTITUTE IN THE INTERNATIONAL ARENA

The Institute is committed to fostering international partnerships, because it believes that the research conducted by its staff benefits tremendously from international collaboration. During 1997/98, staff members played a prominent role on both the regional and the international stage, in participating in symposia and workshops, in research collaborating with colleagues from other countries, through bilateral agreements, and in programmes organized through various intergovernmental bodies.

In fulfilment of its current international obligations, the Institute has the responsibility of representing the South African Government annually at numerous international commissions in support of management of renewable marine resources and environmental conservation. These include, *inter alia*, IWC (International Whaling Commission), CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources), ICES (International Council for the Exploration of the Sea), IOC (Intergovernmental Oceanographic Commission of UNESCO), the London Convention, ICCAT (International Commission for the Conservation of Atlantic Tuna) and ISOM (International Ships Operator's Meeting).

The last General Meeting of CIAC (Cephalopod International Advisory Council), held every three years since 1981, was hosted jointly by the Institute and the South African Museum in Cape Town during September 1997. The meeting formed part of the International Symposium on Cephalopod Biodiversity, Ecology and Evolution, dedicated to the memory of the late Professor J. Z. Young FRS, who died on 4 July 1997. The symposium was preceded by a Workshop on Cephalopod Ecology and Fisheries Management, and followed by a Workshop on Biodiversity of Southern African Cephalopods. In all, 99 scientists from 23 countries attended the CIAC'97 symposium and workshops (Fig. 49), exploring yet again, in the best CIAC tradition, whole new areas of cephalopod research. The proceedings of the symposium will, together with a synthesis of the former workshop, be published in 1998 as a special volume (No. 20) of the Institute's *South African Journal of Marine Science*, under the Guest Editorship of Dr A. I. L. Payne, Director of the Institute.

Autumn 1997 saw the real beginning of research activities associated with the BENEFIT programme, which was inaugurated with a cruise in the Angola-Benguela front region on board the Norwegian R.V. *Dr Fridtjof Nansen* and the German-chartered Russian R.V. *Petr Kottzov*, with several Institute staff taking part. BENEFIT is a cooperative regional initiative, involving Angola, Namibia and South Africa and scientists and financial support from Norway and Germany. Its overall aim is to promote optimal utilization of living marine resources in the three countries bordering the Benguela and Angola Current systems, through the development of human capacity and infrastructure and by increasing knowledge of fluctuations in important fish resources and the role of the environment in these fluctuations. Some of the research results on the dynamics of water masses and growth rate of zooplankton in the region of the Angola-Benguela front obtained during the cruise are reported elsewhere in this issue of *Research Highlights*.

One component of the regional BENEFIT programme requiring specific mention is VIBES (VIability of exploited pelagic fish resources in the Benguela Ecosystem in relation to the environment and Spatial aspects), a project of which the Institute is a partner along with ORSTOM (Office de la Recherche Scientifique et Technique

Fig. 49: Delegates to the CIAC'97 cephalopod symposium and workshops held at the SA Museum (C. Booth)

Outre-Mer, France), French Universities, the University of Cape Town, the University of the Western Cape and other local institutions. The initial 2-year phase of VIBES commenced towards the end of 1997 as part of a Franco-South African bilateral agreement, directed towards providing new tools and information for regional assessment of coastal pelagic resources and their management in the Benguela system. The main objective of VIBES is to study long-term changes in fisheries and pelagic fish recruitment, and their spatial patterns in relation to the environment and adult fish abundance according to different scales of observation. As in BENEFIT, training constitutes a major aspect at both bilateral and regional scales.

Leading experts in the fields of fisheries science, ecosystem analysis and environmental research at the Institute have joined a team from several European countries, as well as Angola and Namibia, to develop the so-called Envifish programme. Envifish, a 3-year project due to commence in 1998, aims to develop appropriate methodologies for improving the sustainable management of small pelagic fish in Angola, Namibia and South Africa, where the catch of these stocks is economically and socially important. Training and capacity building have also been incorporated such that scientific findings can be transferred to management and decision-making in these African countries. The focus is on the identification and quantification of key environmental conditions influencing fluctuations in the recruitment and distribution of small pelagic fish in the Benguela and Angola Current systems. The methodology in Envifish is based on an analysis of satellite imagery, oceanographic, meteorological and fisheries data collected since 1981, using state-of-the-art techniques in oceanographic and statistical sciences. Envifish research objectives are thus companion to those of BENEFIT and VIBES, as well as to the fourth phase of the BEP (Benguela Ecology Programme, 1997–2001), which focuses on demersal and midwater species, and SPACC (Small Pelagic Fishes And Climate Change), initiated in 1994 as part of the GLOBEC international programme.

During 1997, two scientists of the Institute were invited, on the strength of their expertise in seaweed ecology and biological oceanography in upwelling systems, to give lectures to post-graduate students at the State University of Gent, Belgium. These guest seminars formed part of the ZAFR9710 programme *Marine Biology and Nematology*, which supports the exchange of students and lecturers between the two countries within the framework of the Flemish/South African Bilateral Agreement on Science and Technology.

A workshop, organized by FAO (Food and Agricultural Organization), to evaluate the small pelagic resources off the coasts of Angola, Congo and Gabon, was attended by two scientists of the Institute's stock assessment group. The meeting, which took place in Luanda, was an invaluable opportunity for the Institute to contribute to a better understanding of the dynamics of the region's important stocks of sardinella *Sardinella maderensis* and *S. aurita*, and the Cunene horse mackerel *Trachurus trecae*.

Early in 1998, the Institute's Resource Assessment and Modelling group organized an intensive training course in fish stock assessment techniques. Administered through the Zoology Department of the University of Cape Town, the course formed part of the FAO/DANIDA (Danish International Development Agency) project *Training in Fish Stock Assessment and Fishery Research Planning*. The primary objective of the course, to strengthen local capacity in fish stock assessment, was addressed by equipping post-graduate students from historically black universities and fisheries scientists from South Africa and Namibia, through active learning, with a range of methods, including models, that they would be likely to apply in tackling stock assessment problems in southern Africa.

Two other bilateral agreements are also deserving of mention here. Activities of the Fisheries Working Group of the SA/USA Binational Commission continued, generally at a modest pace in terms of collaboration in research, but

with vigour in terms of a proposed fast-tracking capacity building involving the Institute, NOAA (National Oceanic and Atmospheric Administration) and its National Marine Fisheries Service in the USA, some historically black colleges and universities (HBCUs) in the USA and like institutions in South Africa. The idea is to train a significant number of candidates from the formerly disadvantaged community in South Africa in subjects such as fisheries management, science and economics, and oceanography. Much of the training itself will be in the United States, sponsored by US agencies, but much of the on-the-job experience will be generated at the Institute and other research agencies in both countries. The second notable agreement, highlighting capacity building and collaborative research, is with the Institute of Marine Research in Bergen, Norway, supported by the Norwegian Overseas Development Agency (NORAD) and administered through that country's *Fridtjof Nansen* programme. Ecosystem studies, and seaweed and acoustic research are prioritized, but 1998 will also see the agreement initiate training in fisheries management of the first four HBCU graduates in Bergen. Institute scientists are playing a leading role in preparing the four for their studies, and also in supervising the fieldwork and projects.

Effective international cooperation was also carried out in a less formal manner. Since the deployment by South Africa last year of an integrated scheme which monitors fishing vessels on the Patagonian toothfish fishing grounds near the Prince Edward Islands, South African scientific observers have gained an international reputation. As a result, they have subsequently served on fishing cruises aboard British, Japanese and New Zealand vessels fishing for toothfish elsewhere in the CCAMLR zone. Such informal international collaboration through exchange of ship's time or by providing berths for foreign scientists is cost-effective, and offers opportunities for Institute scientists to work in remote areas. For example, in September 1997, Institute staff took part in the Cape-of-Good-Hope Experiment (KAPEX) on board the American R.V. *Seward Johnson*. KAPEX is a collaborative project involving scientists from Germany, the USA, France and South Africa. Some results of this research into the dynamics of Agulhas rings and eddies in the south Atlantic are shown elsewhere in this *Research Highlights*.

These are only some of the highlights illustrating the Institute's involvement in international collaborative marine research (there is no priority in the order of reporting). Some of the publications listed below in this issue of *Research Highlights* should attest further to the Institute's international research alliances.

PUBLICATIONS

In 1997 Sea Fisheries was involved in 124 publications, oral papers and poster presentations. This is 72 less than last year, largely attributable to considerably less contributions (47 in total) to symposia and workshops held this year, in contrast to 144 last year. Interestingly, Institute staff contributed to 58 refereed papers in 1997, compared to just 36 in 1996. There were also 16 contributions by staff to chapters in books on marine vegetation, seaweeds, seabirds and mammals. The 18th volume of the *South African Journal of Marine Science* was published, containing 32 papers, four of which concerning marine protected areas in South Africa.

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